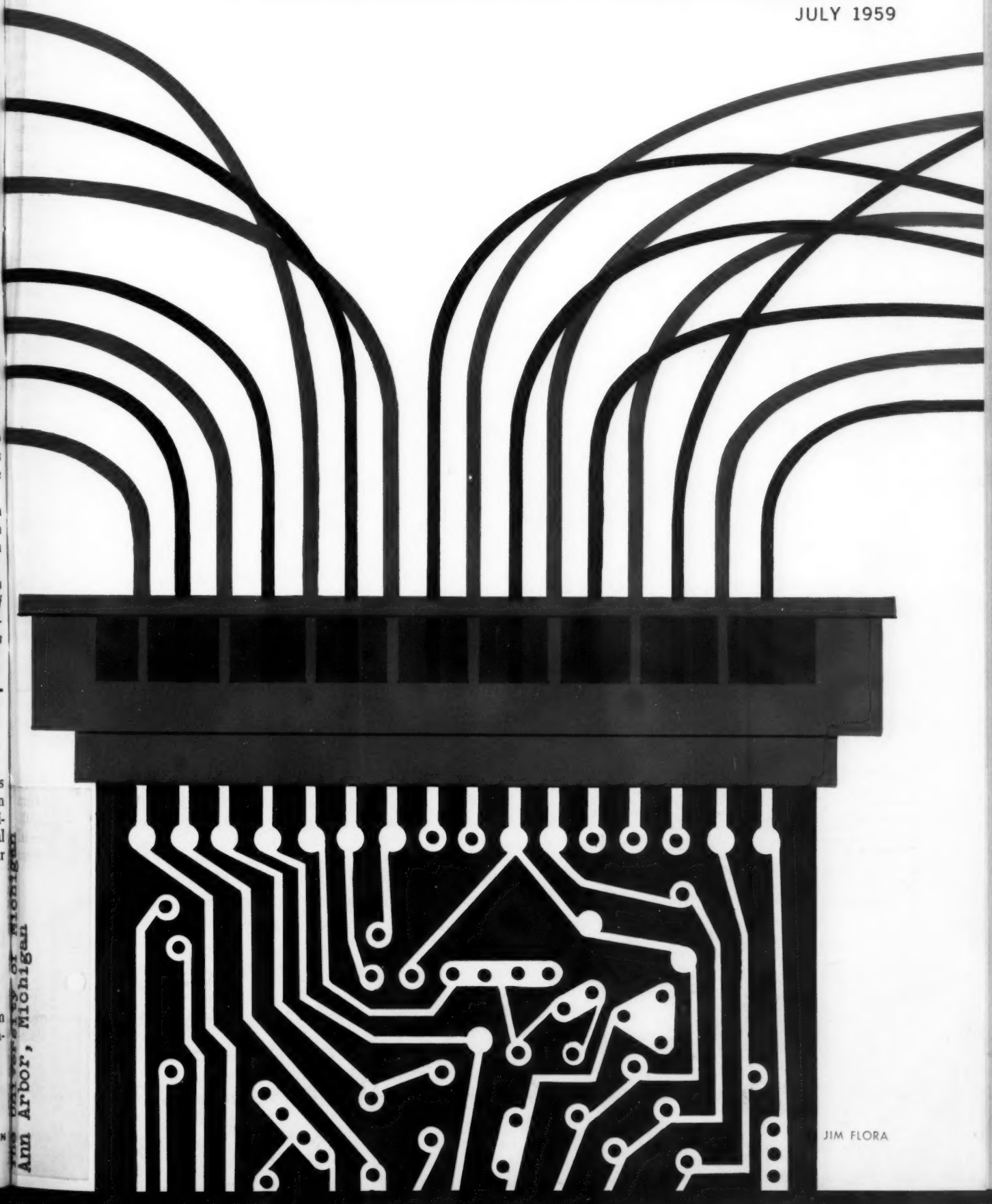
# ELECTROMECHANICAL

## components & systems | DESIGN

JULY 1959



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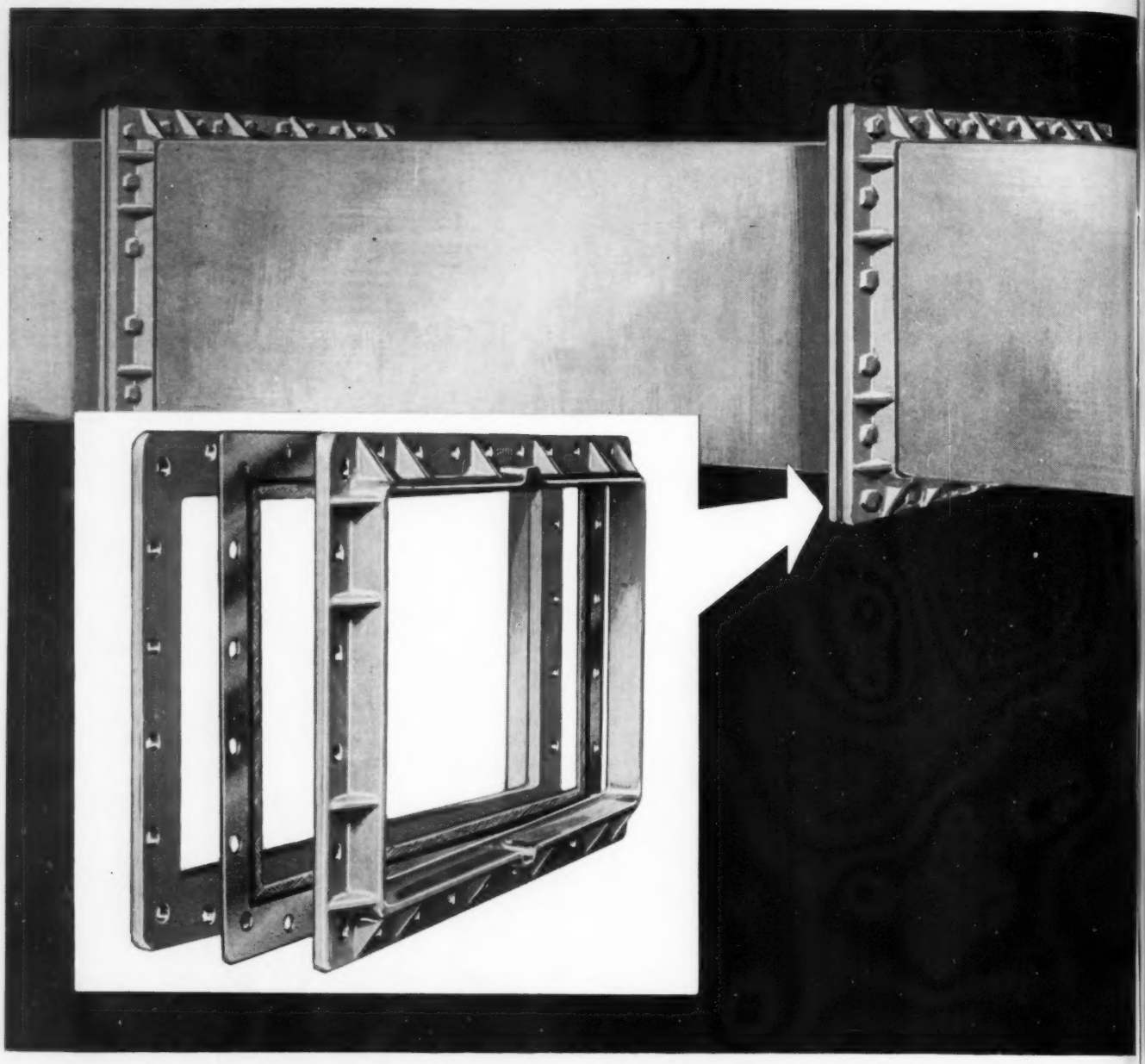
Ann Arbor, Michigan



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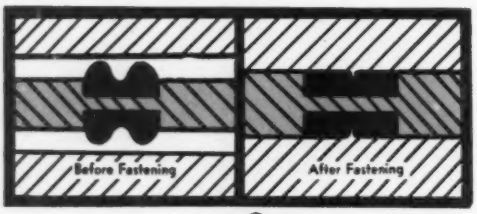


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CIRCLE 1 ON INQUIRY CARD

The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3, NO. 7

JULY 1959

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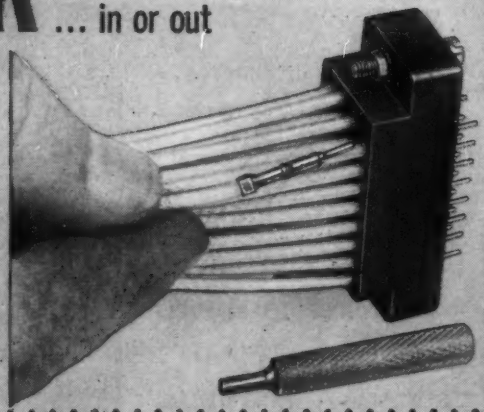

Pins and sockets are easily and quickly snap-locked into plugs and receptacles. They may be removed with a simple extraction tool for circuit changes or checks.

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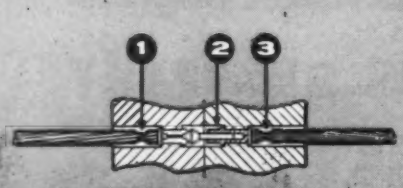


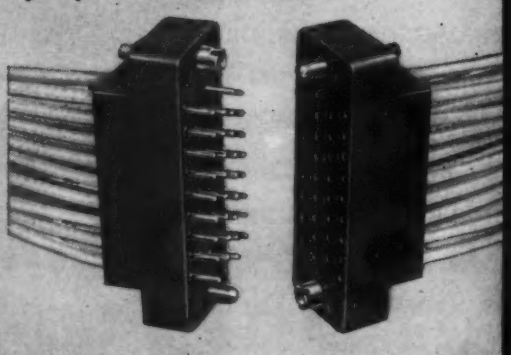

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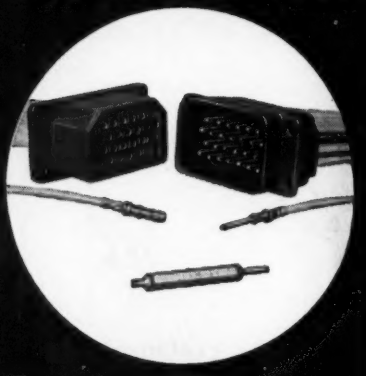
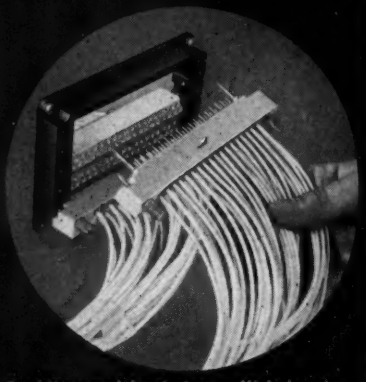
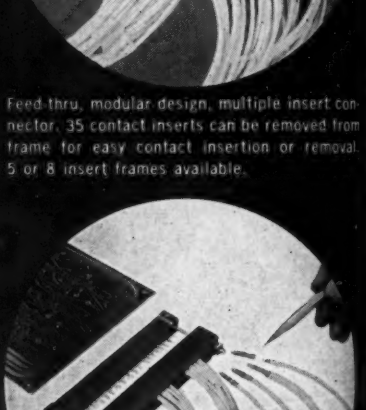


ME rack and panel HYFEN connector. 8 or 26 place configuration. One-piece shell and one-piece block. Also available for coaxial or shielded cable.



Feed-thru, modular design, multiple insert connector. 35 contact inserts can be removed from frame for easy contact insertion or removal. 5 or 8 insert frames available.



Printed circuit connector in either 31 or 45 place configuration. Accommodates single wire or combinations of wire sizes.

HYFEN types illustrated are typical of those already supplied to the industry by BURNDY. HYFEN connectors are engineered to meet specific requirements. For other types or sizes, contact BURNDY.

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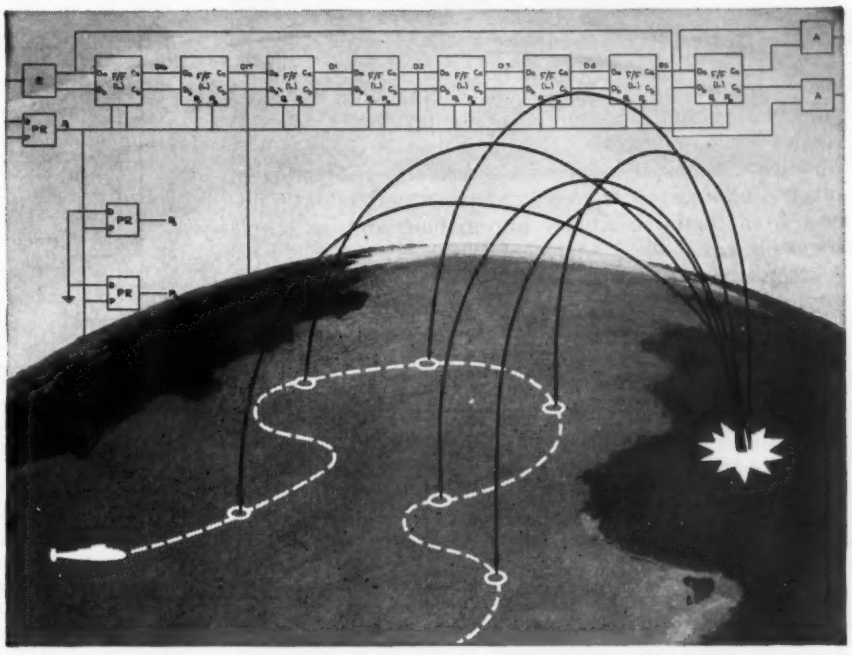

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# LOW COST STEPPER MOTOR

## Magnetic Detent Reduces Shock Load

Primary use of stepper motors is to convert digital computer intelligence to shaft position. Thus, they are a type of digital to analog converter. They find uses in: x-y plotters, positioning of cockpit instrument indicators, positioning of resolvers, induction pots, resistance pots and other transducers from digital computer information, and as simple pulse counters.

A stepper motor that appears to offer advantages in simplicity, reliability, weight and cost over conventional means of converting digital computer output to mechanical position has been built by American Electronics, Inc. at the request of their customers. The new motor consists of a 2-pole PM rotor and wound stator which has 2 ct windings spaced at right angles, resembling a 4-pole stator. When a d-c voltage is applied to one or more of the stator windings the PM rotor will align itself with the resulting stator flux field. When the voltage is switched from one winding to another, the rotor realigns itself in a new direction—it steps. In its present configuration, the motor can be made to step in angles of 45°, 90°, 180° or 360°, depending on the logic used.

A proper sequence of switching of the stator windings will result in uniform consecutive stepping or digital rotation of the rotor. The rotor may be made to rotate continuously (in steps) in either direction or in one or a series of steps alternately in either direction. The maximum random direction stepping rate obtainable with any given stepper motor will normally be approximately 75 percent of the maximum obtainable unidirectional step rate. The maximum obtainable step rate is also determined by the step angle. In general the smaller step angles demand less time per step, thus permitting a higher step rate. However, the circuitry required to switch the step motor is generally more complex for the smaller step angles.

### LOGIC CIRCUITS

Information which controls the direction and number of steps is typically in the form of pulses supplied by digital computer outputs. These pulses are fed into a "step-motor switching logic circuit" which forms the pulse information into proper switching to step the rotor. American Electronics, Inc. does not supply these logic circuits since most users prefer to make their own.

A typical logic circuit would consist of transistors, diodes, capacitors and resistors, and would result in an approximate package size of 1 in. dia. x 2 in. long for 180° steps and 1-½ in. dia. x 2-½ in. long for 90° steps. (See Figs 1 and 2.)

### ADVANTAGES

In addition to having no mechanical parts to wear out or go out of adjustment, the new stepper motor has the advantage that its "magnetic detent" results in a far smaller shock load on the output shaft and subsequent hardware than does a rigid mechanical detent. Moreover, switching transients found in conventional stepper motors are not present in the new device.

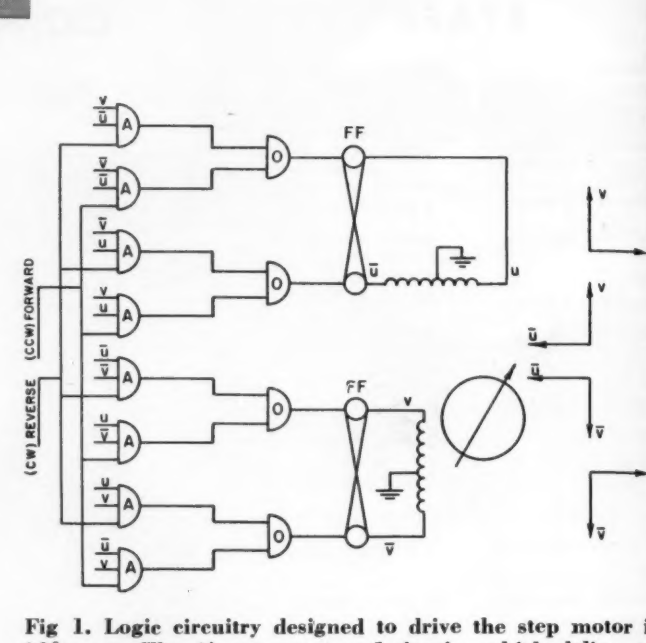


**Fig 1. Logic circuitry designed to drive the step motor in 90° steps. The A's represent *and* circuits, which deliver an output only as long as all the inputs are energized. The O's represent *or* circuits which deliver an output when either of the inputs is energized. The FF's represent flip-flops which change their state according to the channel delivering the last input pulse. The magnetization vectors for the different polarities of energization of the separate coils are shown as *u* and *v*. The circuit is excited by a pulse applied either in the forward (ccw) or the reverse (cw) directions. In a typical illustration, assume that the energization state is such that *u* and *v* are excited. Let us apply a forward pulse. The *and* circuit which responds is the fourth one from the top because only in this circuit are the *u* and *v* channels energized. An output is delivered to the *or* circuit which then changes the *u* on the flip-flop to the $\overline{u}$ mode. This will rotate the output flux vector and the rotor 90° in a counter-clockwise position. The above reasoning may be applied for either forward or reverse pulses for any particular state of energization of the step motor.**

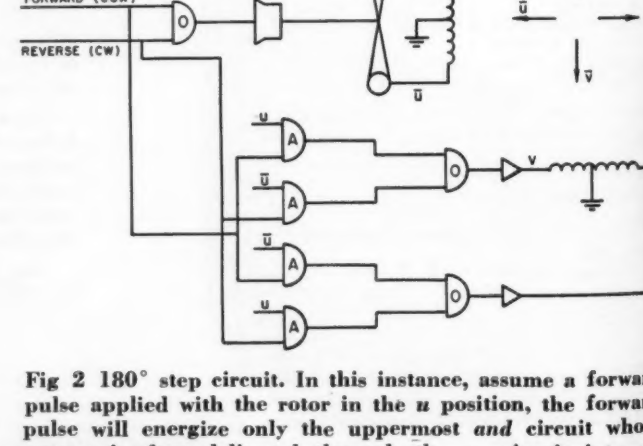


**Fig 2 180° step circuit. In this instance, assume a forward pulse applied with the rotor in the *u* position, the forward pulse will energize only the uppermost *and* circuit whose output is then delivered through the *or* circuit into an amplifier and into the *v* winding. The rotor starts to rotate counterclockwise, however, after a delay, the flip-flop will change state and rotate to the $\overline{u}$ condition. The *v* pulse by now has diminished to zero but the rotor is on its way towards the new $\overline{u}$ position, 180 degrees away.**

The new stepper motor also offers considerable advantage over a servo motor as a position servo operated from digital information. In using a servo motor you have to integrate the pulses and convert them to an analog voltage which in turn must modulate a 400 cps carrier voltage—a complicated operation requiring a fair amount of circuitry. This modulated voltage must then be compared to the voltage from a feedback transducer (synchro, resolver, or pot) on the servo motor output shaft. Finally, these two voltages must be summed in some device and the result fed into a servo amplifier driving the servo motor control winding. The servo amplifier alone is often the size, weight and cost of the entire logic circuit required to operate the stepper motor. In contrast, the stepper motor is a digital input device itself, and may be used without any feedback elements since its shaft position is the sum of all pulses fed into the logic circuit.

In its present form the stepper motor is primarily suited for high speed, low torque applications. Stepping rates of 120 steps/second bi-directional, 160 steps/second unidirectional, with 90° step angles have been obtained in all frame sizes. Running torque at the maximum rate varies from 0.10 to 0.5 in oz depending on the frame size. Torque and inertia loads will reduce maximum stepping rate. Accuracy of step angle is about 2° to 5° for 90° steps. Units are available in standard BuOrd 8, 11, and 15 frames with either terminal boards or leads and can be supplied with all gearheads normally available on these sizes of servo motors.

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## WORTH FILING

### Recorders and Recording Controllers

Twelve-page booklet describes G. E.'s new self-standardizing strip-chart recorders and recording controllers for measurement of electrical and process variables. Included are product photographs, application data, typical control system schematics, specifications, and dimensions. A silicon diode voltage source gives continuous standardization without dry cell, standard cell or standardization mechanism. Variables that can be measured include kilowatts, kilovars, d-c volts, power factor, frequency, time deviation and other electrical quantities plus process variables.

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### Electrical Connectors

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### Electric Process Heaters

Sixty-four page catalog illustrates a complete line of 15,000 types of electric process heaters and describes their many uses. Included are an application section and a technial section to aid in calculation of heating requirements.

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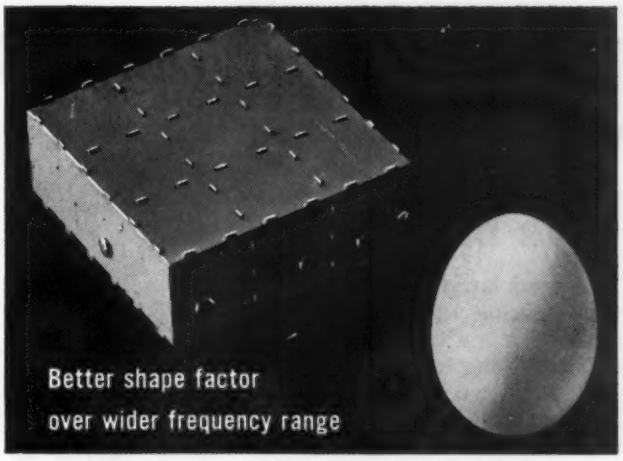


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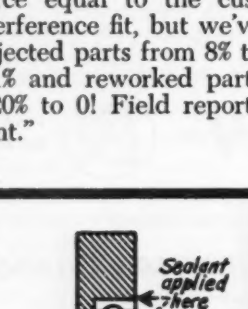


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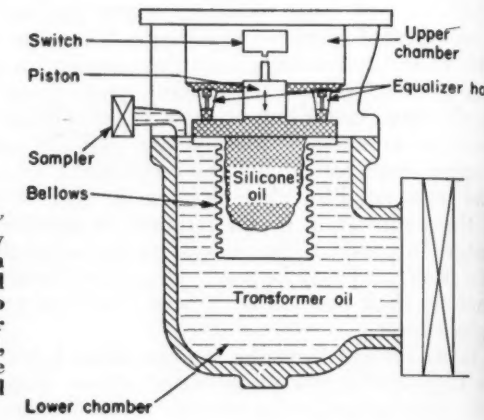


**Cross section of G.E.'s new type J fault pressure relay shows how shock wave in transformer oil is transmitted to bellows, to silicone oil, to piston, to switch. Equalizer holes compensate for normal, slow pressure variations due to changes in ambient and loading.**

## POWER TRANSFORMERS

### Fault Pressure Relay Responds to Internal Transformer Faults

A new fault pressure relay, which incorporates a unique pressure differential or equalizing feature to prevent false operation, prevents power transformers from operating in damaged condition. Called Type J, the relay is designed to respond only to internal transformer faults and not to line through-faults, system surges or mechanical shock and vibration. It signals circuit breakers to open and deenergize the unit.

Normally located on the transformer tank near the base, the J-relay operates from the primary shock wave produced in oil by a fault. G. E. engineers believe that more rapid and accurate response, and hence better transformer protection, is possible when this mounting location is used.

Operation will occur whenever the pressure increases at a rate exceeding 0.5 psi/sec. Response time is about 3 cycles for an oil pressure rate-of-rise of 18 psi/sec. The device operates in one cycle when a major fault occurs.

The J relay's lower chamber contains a silicone-oil-filled bellows, made of phosphor-bronze, and surrounded by transformer oil. In the upper chamber of the device is an additional small quantity of the special silicone oil which is connected to the bellows by two small equalizer holes. A piston rests on top of the silicone oil in the bellows. The fault-shock wave is carried by the transformer oil to the piston via the bellows and silicone oil. The piston then operates the signal switch.

The two equalizing holes assure continued accuracy regardless of variations in the transformer's operating pressure. Should loading or the ambient increase, operating pressure will gradually rise. However, oil will then escape from the bellows into the upper chamber through the two holes, and the relay will compensate for the increased pressure. It is equally responsive to a fault at all pressures in the normal operating range.

Other benefits of the J relay are:

- It can be used with any oil preservation method.
- It is accessible because of floor-level location.
- It can be used with a gas-detecting relay which warns of incipient faults.
- It is easily tested with an air supply and gage plus a stop watch.

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WORTH FILING

### Low-Cost, High-Speed Automatic Recloser

Low-cost, high-speed automatic reclosing protection for 23- to 46-kv circuits is described in a comprehensive new bulletin that illustrates and describes Type HVR reclosers – 23, 34.5 and 46 kv sizes with continuous-current ratings of 100, 140, 200, 280, and 400 amperes—for protecting subtransmission lines and higher voltage distribution lines. The HVR reclosers were developed for applications where more expensive fault-handling switchgear can not be justified and where power fuses are not sufficient because of their inability to restore service automatically after clearing transient faults.

Source: Greensburg Division
I-T-E circuit Breaker Co.
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Take full advantage of the superior electrical and physical properties of High Alumina and Steatite ceramics. Let CENTRALAB provide you with complete assemblies.

The specialized techniques of close tolerance ceramic-to-metal fabrication are daily routine at CENTRALAB. You can eliminate production assembly problems and at the same time achieve superior products by relying on years of expert knowledge and unequalled facilities for engineering ceramics.

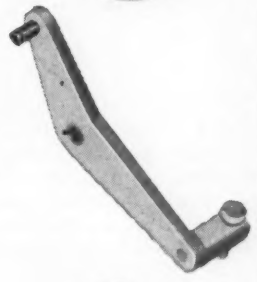
CENTRALAB can handle intricate, precision assemblies involving machining of ceramics or metals to ±.00025, metalizing of ceramics, cementing, riveting, soldering, plating, and stamping. Such assemblies are regularly produced in their entirety—from raw stock—in the CENTRALAB plant.

Write for your free copy of CENTRALAB'S Ceramic Design Handbook giving your detailed design data and complete electrical and physical specifications on High Alumina and Steatite ceramics.

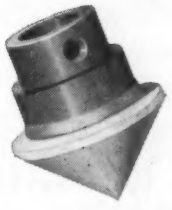
**VARIABLE CONDENSER SHAFT**
Precision 95% High Alumina shaft and silver plated brass hardware assembled and machined to a Total Indicator Reading requirement of less than .002".

**HIGH PRESSURE CONNECTOR**
With eight critical metal to ceramic sealing areas, capable of withstanding a minimum of 3,750 psi. Copper plated stainless steel housing.

**TUNER COUPLING ARM**
To hold center dimensions between riveted brass pivot and cemented phosphor bronze bushing, bushing is machined to a tolerance of ±.0005" or less. O-ring groove on pivot machined to .012" wide, —.000" + .002". Machined ceramic screw.



**NON-FLOATING VALVE SEAT**
Comprised of ceramic cone with surface finish of 3-5 helium light bands brazed to machined and copper plated bushing. After assembly, Total Indicator Reading of ceramic cone is less than .005".



**CONTACT ROTOR ASSEMBLY**
With riveted and soldered contact arm. Nickel plated brass bushing soldered to metalized ceramic. Tolerance —.000" + .001". on I.D. of bushing after slotting.

Centralab
X-5939

A Division of Globe-Union Inc.
**924G E. KEEFE AVE. • MILWAUKEE 1, WIS.**
669 Bayview Avenue, Toronto 17, Canada

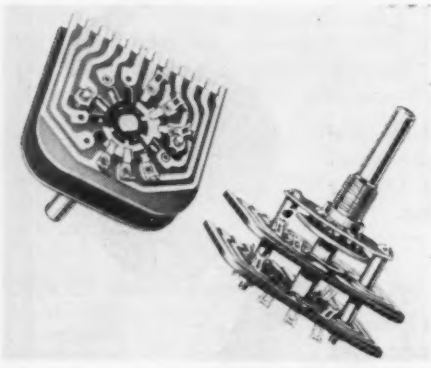
**VARIABLE RESISTORS • ELECTRONIC SWITCHES • PACKAGED ELECTRONIC CIRCUITS • CERAMIC CAPACITORS • ENGINEERED CERAMICS**

CIRCLE 7 ON INQUIRY CARD

# SWITCH SELECTION AIDS

### Printed Circuit Switch

The cost of switch installation can be considerably reduced by means of a new development that Walter E. Peek, Centralab's General Sales Manager calls the greatest advance in switch design in decades. Mr. Peek reported that Centralab's Series 20 printed circuit switch reduces costs considerably because of three major factors: Switch wiring errors are eliminated; all switching leads are connected simultaneously during dip soldering of etched circuit boards; and no hardware is required for rigid anchoring of the switch to the board.



**Printed circuit switch is constructed of laminated phenolic sections 1¾″ high and 2″ wide and is available with bolted construction multiple sections and staked single or dual section assemblies. Design covers combinations from one pole-12 positions through 6 pole-2 positions.**

The new switch series is rated at 2 amperes 15 volts DC, 150 ma. at 110 volts AC (make and break, resistive load). The insulation is laminated phenolic type PBE per specification MIL-P-3115. Voltage breakdown is 1000 volts RMS, and the switches have a rotational life of 10,000 cycles minimum. Centralab has detailed complete physical and electrical specifications on these units in Bulletin EP-757.

Circle No. 82 on Inquiry Card

### Inertia Switch

New compact inertia switch that meets stringent military environmental requirements, can be mounted in any plane to detect acceleration forces caused by roll, pitch, yaw, etc. Standard units are factory adjustable from 1 G to 3 G and special units up to 50 G can be constructed. Operating temperature range −55C to 100C. Accuracy ±5 percent, time constant at 25C is 1 second. Switch is single pole, double throw and can be adjusted for equal or unequal sensitivity from either direction in one plane through the longitudinal axis. Switch reset is automatic and contacts are rated 100 milliamperes at 28 volts DC. The Magnavox Co., Government & Industrial Div., Ft. Wayne, Ind.

Circle No. 133 on Inquiry Card

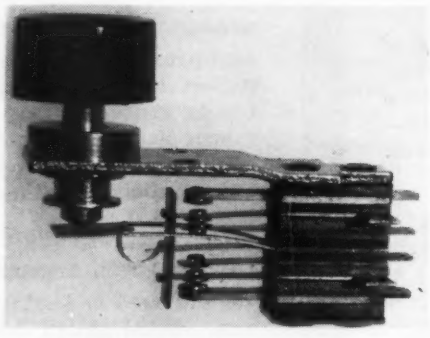
WORTH FILING

### Switch Guide

Electronic and electrical engineers and designers may now obtain a complete bound reference catalog on electrical switches and actuators. This one volume contains a discussion of switch terminology, basic design types, operating methods and environment application data. Also included are photos, dimension drawings, specifications and modification information. Provision will be made to keep all issued copies up-to-date with periodic issuance of supplementary technical data.

Source: Electrosnap Corp.
Chicago 24, Ill.

For your copy: Circle No. 200 on Inquiry Card



### Push Button Switch Performs Double Function

A small open blade, push button switch designed for mounting through a panel features double pole, double throw circuitry and performs the functions of two separate switches with resulting savings in cost and space. It is rated at 10amps, 125 vAC, has gold flashed contacts and is available with palladium contacts for low contact forces, small currents and small impressed voltages. Acro Div., Robertshaw-Fulton Controls, Columbus, O.

Circle No. 188 on Inquiry Card

### Impact Switch Registers

A new type impact switch, with only two moving parts, opens or closes an electrical circuit in response to a predetermined amount of shock, from any direction within 90 degrees of the vertical axis. It may be used to arm a fuze or warhead, activate a beacon or alarm, start or stop a machine. A common airborne use is disconnect and deployment of parachutes from grounded target drones. Four features, previously unavailable on impact switches, include omni-directional actuation in the lower hemisphere, reliability through circuit redundancy, high current carrying capacity and provision for ground checkout. George Harmon Co., Northridge, California.

Circle No. 219 on Inquiry Card

WORTH FILING

### Precision Switch Catalog

New 28-page catalog contains comprehensive data on new sealed switches for severe environments and new low-cost switches for mass-produced automatic devices, household appliances, etc. added to complete descriptions of general-purpose, low-force, high-sensitivity, open-blade, environment-free, metal cased, AN and JAN, direct current and reset switches. Also shown are a wide variety of integral and auxiliary actuator styles.

Source: Unimax Switch Div.
The W. L. Maxson Corp.
Wallingford, Conn.

For your copy: Circle No. 204 on Inquiry Card

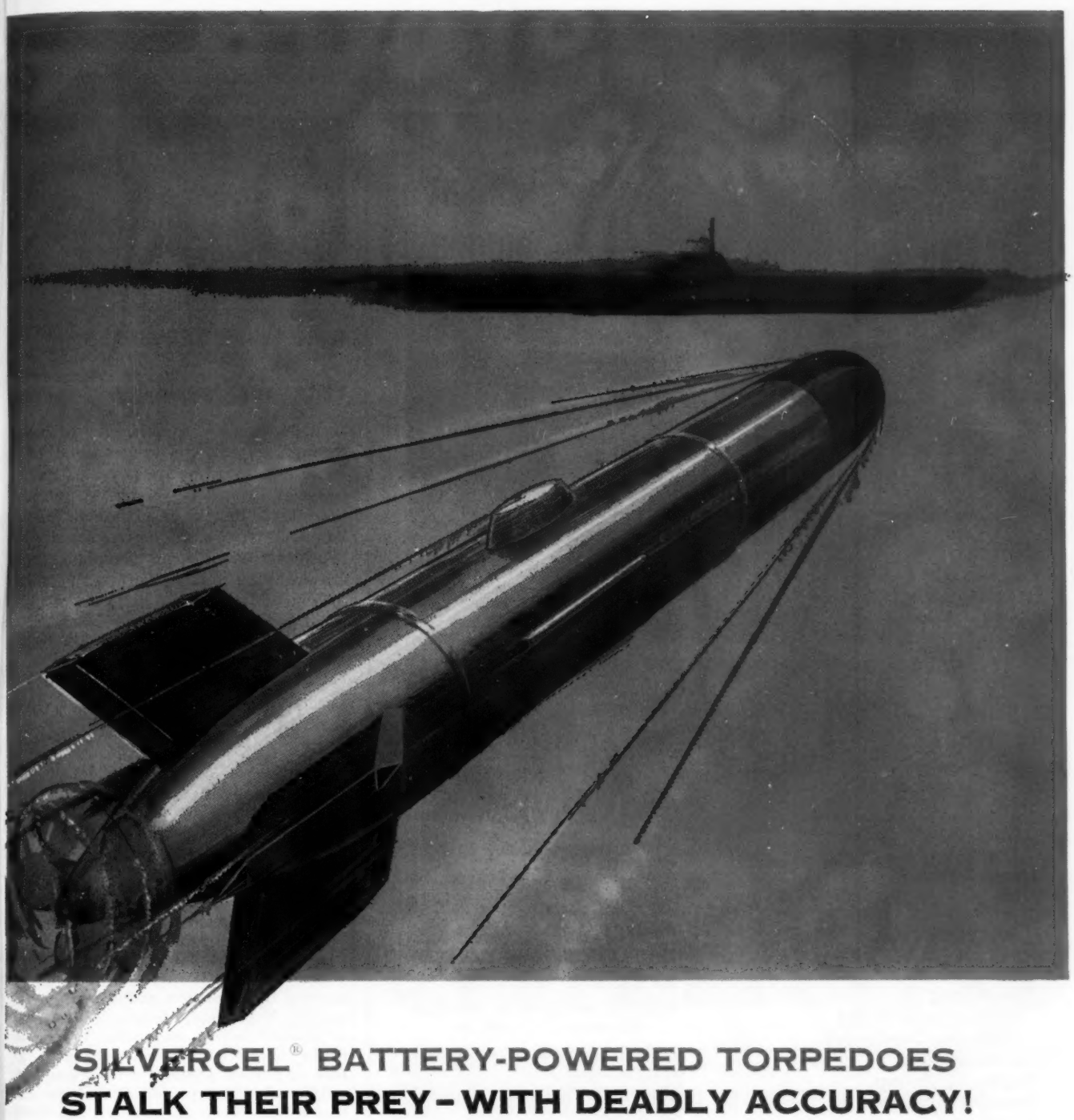
WORTH FILING

### Subminiature-Switch Catalog

16-page catalog describes subminiature switches that meet Military Specs. It includes information on high-temperature (650°F) switches and metal enclosed, environment-free switches as well as popular types of phenolic-cased, push-button, toggle, and integral-actuator subminiature switches. Convenient pictorial index shows where to find dimension drawings, descriptions, force and movement specification tables and electrical ratings for each Unimax subminiature switch listed. Data on bases, terminals, circuit arrangements and NEMA standard definitions of sensitive switch terms are also included.

Source: Unimax Switch Div.
The W. L. Maxson Corp.
Wallingford, Conn.

For your copy: Circle No. 201 on Inquiry Card



# SILVERCEL® BATTERY-POWERED TORPEDOES STALK THEIR PREY – WITH DEADLY ACCURACY!

Through every stage of their stalking missions, the Navy's revolutionary torpedoes depend on YARDNEY SILVERCEL® BATTERIES to power remarkable propulsion and homing devices.

From the largest and most complex missile to the smallest subminiature device, today's advanced technology requires maximum energy from a package of minimum size and weight. As in torpedoes, YARDNEY SILVERCEL® BATTERIES provide reliable energy with only 1/5 the size and 1/6 the weight of ordinary batteries. They are used in 19 U. S. missiles...including major intercontinental and intermediate-range missiles.

Write today for complete technical data and literature to find out how you can gain needed power, save vital space and weight.

## YARDNEY ELECTRIC CORP.

*"Pioneers in Compact Power"**

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*Patents granted and pending.*

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**Trade Mark*

MANUFACTURERS OF YARDNEY SILVERCEL®, YARDNEY SILCAD® AND YARDNEY ARCTIC* BATTERIES

CIRCLE 8 ON INQUIRY CARD

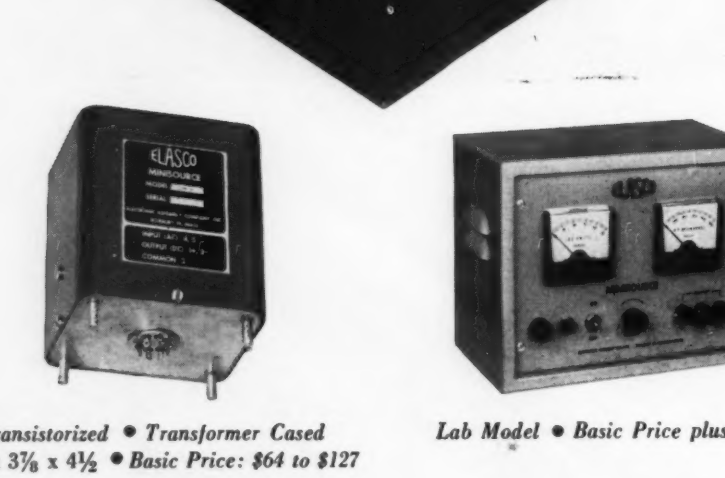
# power supplies



*Transistorized • Transformer Cased*
*3 5/16 x 3 7/8 x 4 1/2 • Basic Price: $64 to $127*



*Lab Model • Basic Price plus $60*



*Rack Mounted • Basic Price plus $50*

MINISOURCE Power Supplies

100% SERVICEABLE

No Potting
Printed Circuit Design
Accessible Components

Full Wave Bridge
Flexible E&I Ratings
Standard units from 5 to 50 volts at currents from 50 to 500 ma or units designed and built to customer specifications.

**INPUT:** 105—125 V AC

**REGULATION:** better than 0.5%

**RIPPLE:** better than 0.5%

**OUTPUT IMPEDANCE:** less than 0.25 ohms, DC—100 kc

**POLARITY:** grounded or floating operation

**TEMPERATURE:** compensated from —10 to 55C

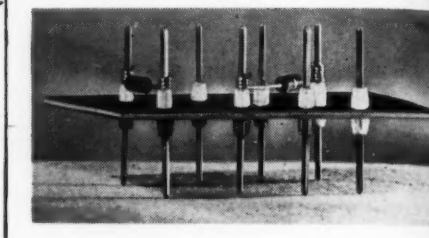
**PRICE RANGE:** Indicated below each unit

**Send for complete catalogue**

# Elasco

CIRCLE 9 ON INQUIRY CARD

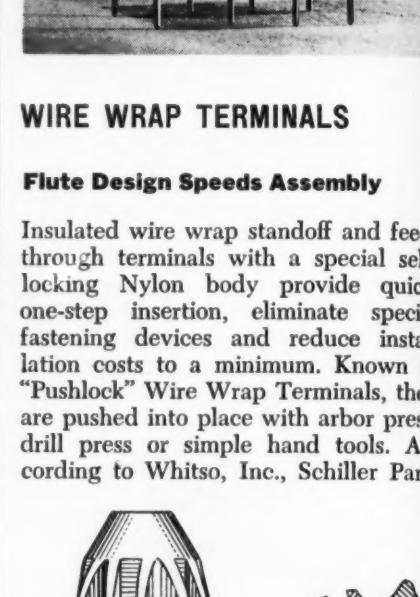


## WIRE WRAP TERMINALS

### Flute Design Speeds Assembly

Insulated wire wrap standoff and feed-through terminals with a special self-locking Nylon body provide quick, one-step insertion, eliminate special fastening devices and reduce installation costs to a minimum. Known as "Pushlock" Wire Wrap Terminals, they are pushed into place with arbor press, drill press or simple hand tools. According to Whitso, Inc., Schiller Park, Ill, they align perfectly and self-lock securely, providing a solid anchor and complete insulation between terminal and plate.



**Construction of the "Pushlock" Wire Wrap Terminal is such that a series of molded flutes project radially from the molded Nylon body. When the terminal is pressed into a mounting hole, the flutes deflect and their tendency to return to normal position creates positive, uniform holding power around the entire inside circumference of the hole. Since the flutes are molded from Nylon, they will continue to exert this pressure under temperatures from —65° to +300° and with exposure to oils, greases and common solvents.**

Holding action and electrical properties of the wire wrap terminals were designed for aircraft, missile, marine, automation, and appliance applications where shock and vibration are serious problems. Their small size and simple design make it possible for them to be used with printed circuitry and miniaturized equipment. Sample available.

Circle No. 78 on Inquiry Card

### Precision Wirewound Resistors

Special precision wirewound resistors with any specified temperature coefficient between −25 and +6000 parts per million per degree C are now available in values of 10 ohms to 3 megohms. The new resistors have application in telemetering, zener diode and other circuits requiring positive temperature compensation. In bridge circuits, they can be used to accurately measure temperature. Characterized by close tolerance and compression molding in an alkyd resin, they are available with solder lugs and axial, radial printed circuit, or special leads, and meet or exceed all applicable military specs. Ultronix, San Mateo, Calif.

Circle No. 222 on Inquiry Card

### Micro-Miniature Relay

Contact contamination—one of the greatest problems in achieving relay reliability—has been significantly reduced by the use of all-welded construction in a new micro-miniature relay. Solder flux has been one of the primary causes of relay contact contamination. The new four-pole, double-throw relay is assembled—without using solder—by an inert arc welding process which hermetically seals the header to the can. Weighing about one ounce, the relay is rated two amperes at 26.5 volts d-c or 115 volts a-c, and is d-c operated using a highly efficient E-type magnet. It is rated from 160 degrees C continuous ambient down to −65C, has a mechanical life of over ten million operations, and electrical life at rated load in excess of 200,000 operations. Operate and release times are six and four milli-seconds respectively, including bounce. Pickup power is 400 milliwatts. The relay withstands vibration tests to 2000 cycles per second at 30 G's and shock tests at 50 G's for 11 milli-seconds. General Electric Company, Schenectady, New York.

Circle No. 224 on Inquiry Card

WORTH FILING

### Printed Circuit Connector Catalog

Twenty-four page catalog covers a wide variety of printed circuit connectors which accommodate 1/16", 3/32" or ⅛" printed circuit cards. Available in single and double row contacts, with up to 116 on one molding, the connectors come in various wiring styles and molding compounds. Also included are complete specifications, outline dimensions, general information and suggested applications.

Source: Electronic Sales Div.
DeJur-Amsco Corp.
Long Island City, N.Y.

For your copy: Circle No. 191 on Inquiry Card


**GRC tiny die castings**
**made in one fast automatic operation ...simple or intricate parts, high in quality, low in cost**

Gries' exclusive patented methods make possible wide design latitude . . . assure uniformity, accuracy and smooth surfaces on small parts of all types . . . for a wide variety of uses . . . at substantial savings. GRC die castings leave the machines trimmed, ready-for-use. In addition GRC's unique single cavity die casting techniques offer new shortcuts in assembly . . . new approaches in product design through our exclusive . . .

**tiny zinc die castings**

NO SIZE TOO SMALL! Maximum sizes up to 1¾", ½ oz.

Write for fact-filled booklet "Small Zinc Alloy Die Castings," includes helpful designer's check list.

GRIES

**GRIES REPRODUCER CORP.**
*World's Foremost Producer of Small Die Castings*
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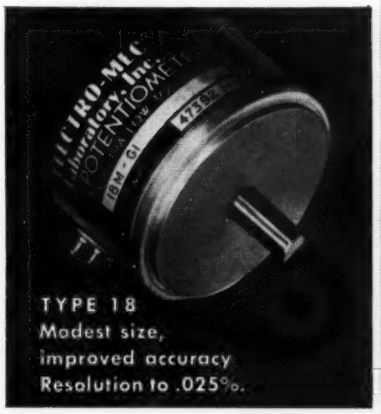
CIRCLE 10 ON INQUIRY CARD

***Predict performance!***
***Cut costs!***
***The key to dependable system performance is***

**RELIABILITY!**




TYPE 18
Modest size,
improved accuracy
Resolution to .025%.

Designers everywhere insist on the rugged reliability of precision potentiometers by Electro-Mec.

- 100% inspection of all vital characteristics.
- Glass insulated terminals.
- 18K gold slip rings.
- Ultra-dependable resistance elements artificially aged to insure stability.
- Exclusive long life wiper design incorporates precious metal contacts.
- Built-in safety factors.

All AIA Sizes .875" to 3.00" Dia.
For complete technical data write to our engineering department.

**ELECTRO-MEC Laboratory, Inc.**
47-51 33 Street
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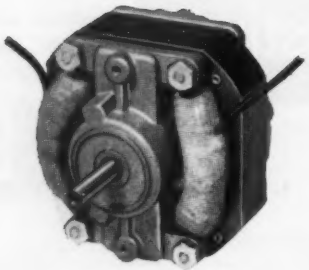
CIRCLE 52 ON INQUIRY CARD

# New! Complete, Expanded Line of Shaded

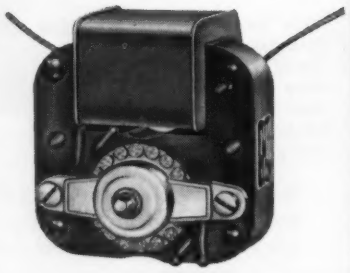
# HOWARD

Newly expanded with the recent additions of the former Fairchild and Scruggs models, the all-inclusive Howard line of shaded pole and induction motors is now the most comprehensive in the industry. The wide selection of standard shaded pole and induction models offered by Howard assures you of a motor to meet your *exact* requirements at low cost and with minimum delay. Thousands of specs are on file so that variations of any standard model can also be quickly and inexpensively supplied. Shown on these pages are just a few of the shaded pole and induction motors in the Howard line. For samples and prices or information on these or other Howard motors—Universal, Gear motors or Blowers (not shown)—send us details of your application today.

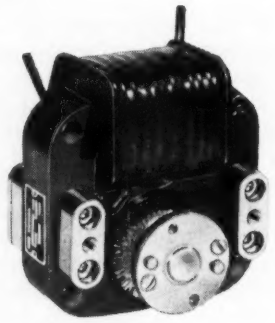
## *Shaded Pole Motors 1/2000 to 1/8 H.P.*



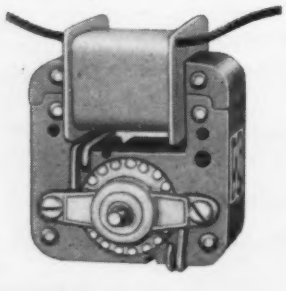
**MODEL 100**
TYPE: 4 pole, double bearing
DIAMETER: 2-3/4 square
LENGTH: 2-5/32 to 2-29/32 depending on stacking
H.P.: 1/650 to 1/85
NO LOAD RPM: 1700
FULL LOAD RPM: 1500 standard
BEARINGS: Sintered bronze, self-aligning type or ball bearings. Extension oil tubes available.



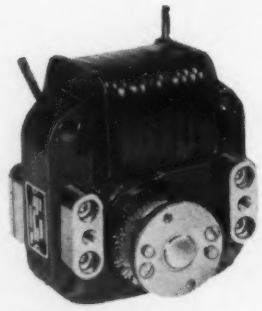
**MODEL 1000**
TYPE: 2 pole, double bearing
WIDTH: 2-3/8
HEIGHT: 2-19/32
LENGTH: 1-5/8
H.P.: 1-1000 to 1/75
NO LOAD RPM: 3400 - 3500
FULL LOAD RPM: 2800 - 3200
BEARINGS: Oilite with large oil reservoir.



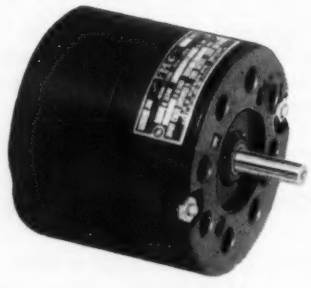
**MODEL 1075**
TYPE: 2 pole, unit bearing
WIDTH: 2-3/8
HEIGHT: 2-5/8
LENGTH: 1-3/4
H.P.: 1/750 to 1/185
NO LOAD RPM: 3400
FULL LOAD RPM: 2600 - 3200
BEARINGS: Unit bearing construction with permanently sealed-in lubrication.



**MODEL 1100**
TYPE: 2 pole, double bearing
WIDTH: 2-1/2
HEIGHT: 2-15/16
LENGTH: 1-1/2 to 2 depending on stacking
H.P.: 1/750 to 1/50
NO LOAD RPM: 3400
FULL LOAD RPM: 2800 - 3200
BEARINGS: Oilite with large oil reservoir.



**MODEL 1175**
TYPE: 2 pole, unit bearing
WIDTH: 2-1/2
HEIGHT: 2-31/32
LENGTH: 1-49/64 to 2-5/8 depending on stacking
H.P.: 1/700 to 1/100
NO LOAD RPM: 3400
FULL LOAD RPM: 2600 - 3200
BEARINGS: Unit bearing construction with permanently sealed-in lubrication.



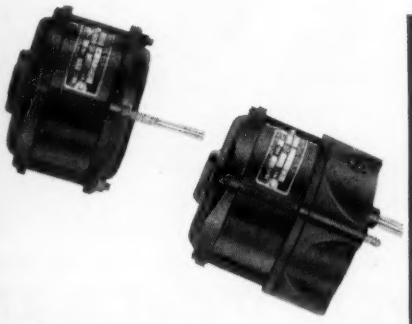
**MODEL 2800S Stamped Steel Case**
TYPE: 2 pole or 4 pole shaded pole
DIAMETER: 3-9/32
LENGTH: 2-3/16 to 3-1/16 depending on stacking
H.P.: 1/100 to 1/30*
NO LOAD RPM: 1700 or 3400
FULL LOAD RPM: 1500 or 3000
STARTING TORQUE OZ. IN.: 2.0 - 10.0 depending on stacking
BEARINGS: Porous bronze sleeve type with large oil reservoir.
*Ratings are continuous duty, 55° C rise in a 40° ambient, with air drawn over the open ventilated motor.

CIRCLE 11 ON INQUIRY CARD

# Pole and Induction Fractional H. P. Motors

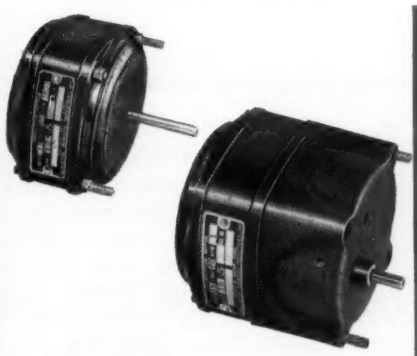
*Now Offering the Widest Selection of Motors and Prices in the Industry!*

*Induction Motors 1/1400 to 1/4 H.P.*



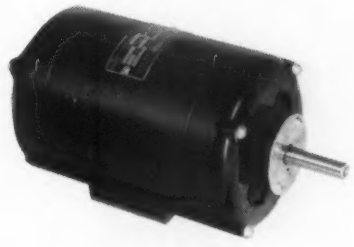
**MODEL 2400**

TYPE: 4 Pole Induction.
DIAMETER: 2-9/16" square.
LENGTH: 2-3/8" to 3".
SINGLE PHASE CAPACITOR MOTOR.
Maximum Torque oz in.—1.
Full Load Speed R.P.M.—1150.
Bearinge—RBC—Ball. RWC—Sleeve.
TWO PHASE MOTOR:
Maximum Torque oz. in.—1.5.
R.P.M.—1150.
Bearings—RBC—Ball. RWC—Sleeve.
BEARINGS: Porous bronze sleeve type with oil reservoir, or grease sealed ball bearings.



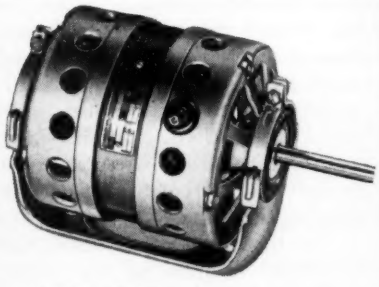
**MODEL 2500**

TYPE: 2 pole or 4 pole induction.
DIAMETER: 2-9/16" square.
LENGTH: 1-7/8" to 2-3/8".
SPEED: *1200 to 3600 R.P.M.
H.P.: 1/300 to 1/1400.
MAXIMUM TORQUE OZ. IN.: *1.6 to 3.5.
BEARINGS: *Ball or sleeve.
*Dependent on type of motor used, i.e. Non-Synchronous Capacitor Motors, Torque Motors, Standard Synchronous Motors, Hysteresis Synchronous Motors.



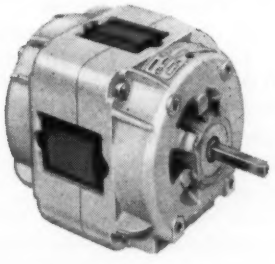
**MODEL 2900**

TYPE: 2 Pole, 4 Pole, 6 Pole or 8 Pole Induction.
DIAMETER: 3-5/16".
LENGTH: 4-25/32" to 5-21/32" ball bearing.
5-5/16" to 6-3/16" sleeve bearing.
H.P.: *1/70 to 1/15.
FULL LOAD TORQUE OZ. IN.: *10.0 to 30.
BEARINGS: Bronze sleeve type with oil reservoirs, or permanently lubricated sealed and shielded ball bearings.
*Dependent on type of motor used: i.e. Non-Synchronous Capacitor Motors, Standard synchronous, Motors, Hysteresis Synchronous Motors. Torque Motors.



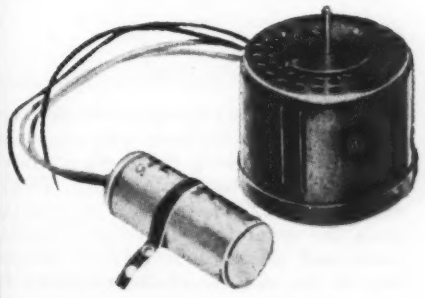
**MODEL 3700**

TYPE: 2 Pole, 4 Pole, 6 Pole or 8 Pole Induction.
DIAMETER: 3-7/8".
LENGTH: 5-1/16" to 5-11/16".
H.P.: *1/25 to 1/7.
STARTING TORQUE: *13 oz. in. to 30 oz. in.
BEARINGS: Porous bronze type with oil reservoir.
*Dependent on type of motor used; i.e. Normal Induction Motor, Hysteresis Synchronous Motor.



**MODEL 9200**

TYPE: Induction, torque, synchronous 2, 4, 6 or 8 poles, 25 to 60 cy single (capacitor) two or 3 phase.
H.P.: 1/250 to 1/50 continuous or intermittent duty.
R.P.M.: 900 to 3600.
DIMENSIONS: 2-7/8" x 2-7/8" by 4-1/32" to 4-13/32".
MOUNTING: Pad, resilient ring, face extended bolts.
BEARINGS: Porous bronze sleeve, (ball bearings available at request).



**MODEL 1**

TYPE: Hysteresis Type Single Phase Capacitor
DIAMETER: 2-5/8
LENGTH: 2-3/16
H.P.: 1/500 to 1/200
SPEED: 3600 RPM
FULL LOAD TORQUE OZ. IN.: .6 to 1.35
BEARINGS: Sleeve or ball.

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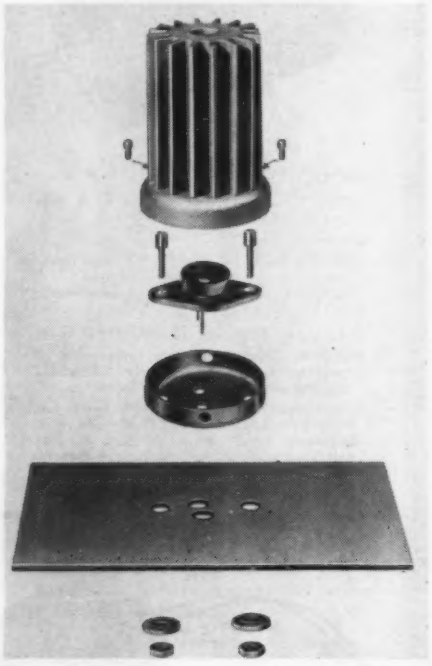
CIRCLE 12 ON INQUIRY CARD

## COMPONENTS DESIGN

### Heat Sink for Power Transistor

Transistor heat dissipator design provides transistor temperature reductions that permits use of 60% less heat sink area. Designed by International Electronic Research Corporation after more than one and one-half years of research and testing, the heat sink's effectiveness in conduction, radiation and convection characteristics are shown by the typical result obtained with a TO-3 germanium type resistor. The transistor, with a maximum junction temperature of 90C could not be operated at more than 2½ watts without a means of dissipating its generated heat. The same transistor



**Major component of the heat sink is a vertical, cylindrical form with numerous radiating fins along the vertical dimension of particular depth, radii, fluting and number. Core area is a resulting mass for primary conduction. Physical form and dimensions vary in proportion to the size dissipator required for a particular transistor. A shallow-rimmed base, of circular shape with appropriate mounting holes completes the assembly. The base serves as an important medium for providing best surface-to-surface mounting and maximum conduction of heat from the transistor to the dissipator. The heat sink is available in various heights for application to any power transistor in a TO-3 case.**

can be safely operated at 10 watts when fitted with an IERC heat dissipator unit on a 2″ x 2″ aluminum plate. In keeping with the small size of transistors, the IERC components are small, light and especially compatible with packaging requirements.

Circle No. 86 on Inquiry Card

### RF Receptacle for Printed Wiring

A simple means of connecting coax cable to printed wiring is the "ConheX" Type 3007 receptacle. It is made of hex stock with four (4) milled studs of rectangular cross section by which the receptacle is attached to the wiring board by dip soldering. The center contact is rigidly held in the assembly between two insulators, allowing no longitudinal or rotating movement, and is also soldered to the printed wiring on the face of the board. Sealectro Corp., Mamaroneck, N. Y.

Circle No. 134 on Inquiry Card

### High Frequency Inverter

General purpose inverter for use in missiles, aircraft and other applications where primary a-c power frequency is 2000 cps, provides sine-wave power from any d-c source without filtering. Input voltage: 22-29 volts DC with transients per MIL-E-5894A. Output voltage: 115 volts ±5%, 2000 cps ±1%, single-phase, 0-50 VA. Waveshape: Sinusoidal with less than 5% total harmonic distortion. Regulation: Output voltage and frequency within above limits for all combinations of line and load. Protection: Cannot be damaged by overload, short circuit, or open circuit operation. Returns to normal output immediately upon removal of overload or short. Size: 3 x 3 inch base, 4 inches high. Weight: 3 lbs. Operating Temperature: −20C to +85C at mounting base. Heat sink required. Vibration: Up to 10G from 2000-3000 cps. Acceleration: 12G. Shock: 40G, 5MS. Atmospheric Pressure: 0.0 to 30.0 inches of mercury. Humidity, dust, sand, fungus and salt spray protected as per MIL-E-5272B, Procedure 1. Power Sources, Inc., Burlington, Mass.

Circle No. 228 on Inquiry Card

### S-Band Power Amplifier

Rated at 3 Mw peak, 15 kW average power output, the QK622 is a new S-band power amplifier stage with wide RF bandwidth. This tube supplies full power over an operating band of 2900 to 3100 Mc at efficiencies greater than 70%. Operating life of more than 1000 hours at rated power output has been demonstrated. Phase stability and pulse stability are excellent. No heater power is required for starting or during operation. The QK622 can be operated at reduced peak power level to serve as a driver stage. High efficiency is retained at a peak power output of 600 kW and gain of 10 db. Raytheon Mfg. Co., Waltham, Mass.

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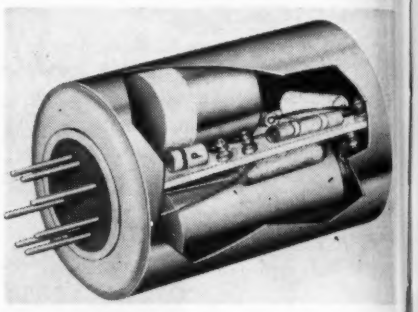
### Voltage Reference Maintains Standard Cell Stability

A voltage reference, extremely stable over wide variations in input and environment, has a 1-VDC output operating into 1000 ohms. It holds this output to within ±1.2 millivolts over input conditions from 100 to 130 VAC, at frequencies from 25 cps to 10,000 cps. The 1-volt output is maintained



over an operating temperature range of −55C to + 100C, and any combination of specified variations in temperature and power input. Unit is designed to meet MIL-E-5272A. Dimension: 1.75″ long x 1.35″ dia. Unit weighs 3 oz., and mounts in any position. Regulator is used as a reference voltage source in power supplies, metering circuits, and strip chart recorders. Networks Electronic Corp., Van Nuys, Cal.

Circle No. 187 on Inquiry Card

### Internal Pinion Counter For Vertical Scale Applications

New miniature internal pinion counter, for digital displays on airborne fuel flow indicators, for navigational and dead reckoning components and for a variety of vertical scale indicating panel applications, provides indications from 0000 to 9999 with return to 0000 in one unit increments. It may be supplied optionally as a three drum counter for three digit indication. Counterclockwise rotation of the right hand shaft provides increasing readings; one revolution advances or reduces the counter 10 units. The unit, conforming to MIL-E-5272A, is designed for continuous operation at 300 rpm and may be operated intermittently at 600 rpm. Bowmar Inst. Corp., Ft. Wayne, Ind.

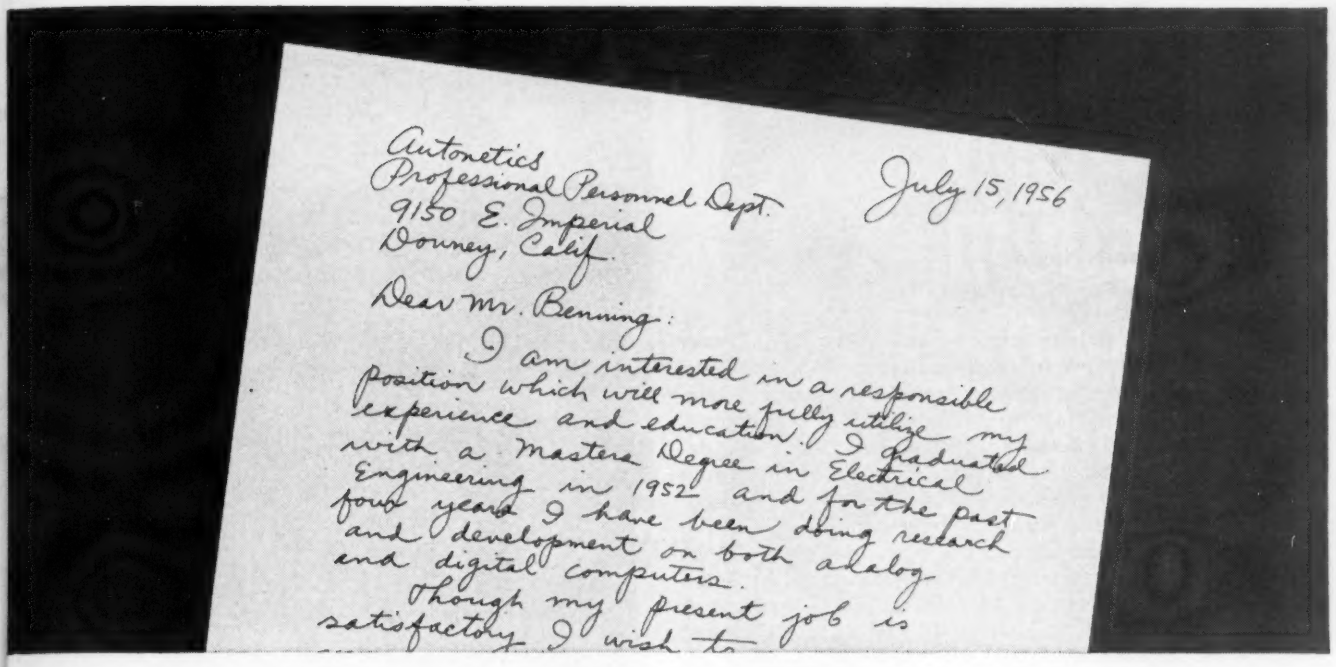
Circle No. 206 on Inquiry Card

WORTH BUYING

### Convenient Tables and Formulas

This book includes 120 pages of convenient tables, formulas and graphical symbols summarizing electrical data, properties of materials, heat transfer and steam information, measurements, and other subjects. Price 50 cents.

Source: Westinghouse Electric Corp. Pittsburgh, Pa.



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## GROUND SUPPORT EQUIPMENT

### Count-Down Monitoring of Multiple Voltage Power Supplies

ICBM launchings require precise, multiple-voltage power supplies to insure proper function of myriads of components, including fuel pressures, valve control and guidance system. Monitoring must be fast, positive and highly accurate. Helipot Division of Beckman Instruments, Inc. has developed such a monitoring package for the Titan ground support system. It provides semi-automatic "go, no-go" indication and response for the voltages on a 3-phase, 400 cycle, 115-volt, a-c and 28 volt d-c power supply. Voltage of each a-c phase is monitored by an individual expanded scale meter to an accuracy of ±0.1%; the d-c circuit is monitored to ±1%. Ken McCoig of Helipot's Equipment Engineering Section explained the design principles applied in this system.

The system employs meter relays manufactured by Assembly Products, Inc., and uses a standard meter movement with the addition of high and low limit contacts mounted on adjustable pointers. Contact pointers may be individually adjusted to desired high- and low-limit values. Locking coils, wound on the same form as the regular meter moving coil and connected in series with the meter contacts, augment the meter movement contact pressure. Contact pressure is increased by closure of a contact that causes relatively heavy current flow through the locking coil.

Figure 2 shows a typical indicator circuit. In this the phase is determined by one inductive and two resistive

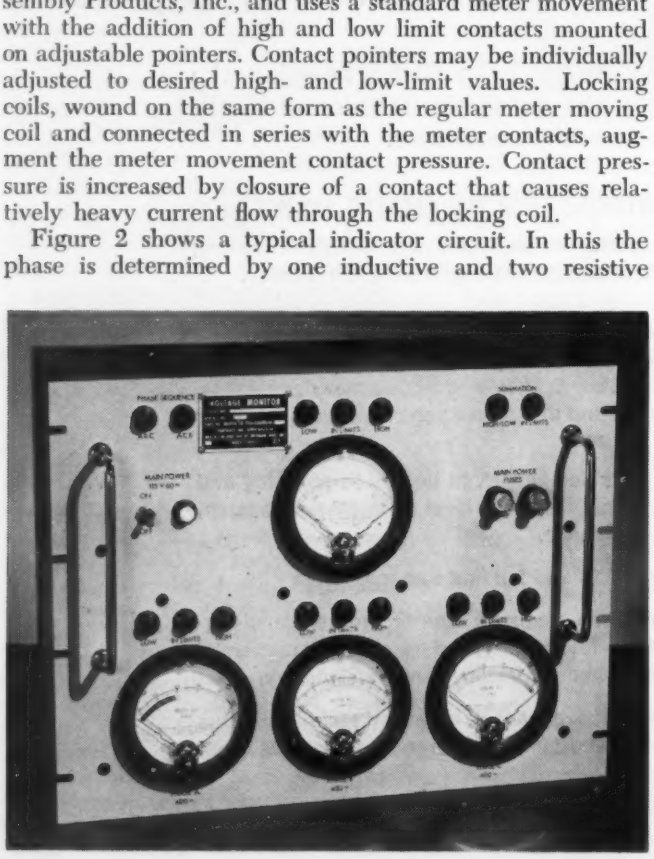

**Fig. 1 All four meters use relay movements to control green "In Limits" and red "High" and "Low" warning lights. In addition, two lights display "AC Phase Sequence" and another pair indicate either a "High/Low" or "In Limits" summation of all monitored voltages. High and low limits are easily set to any point over the meter range. When the entire power supply is operating within the preset limits, all green warning lights glow continuously. If any of the monitored voltages are out of limits, the red summation light glows and the particular section at fault is pinpointed by its own warning light. All lights and relays operate from an independent 115-volt source and can be duplicated at a remote location.**

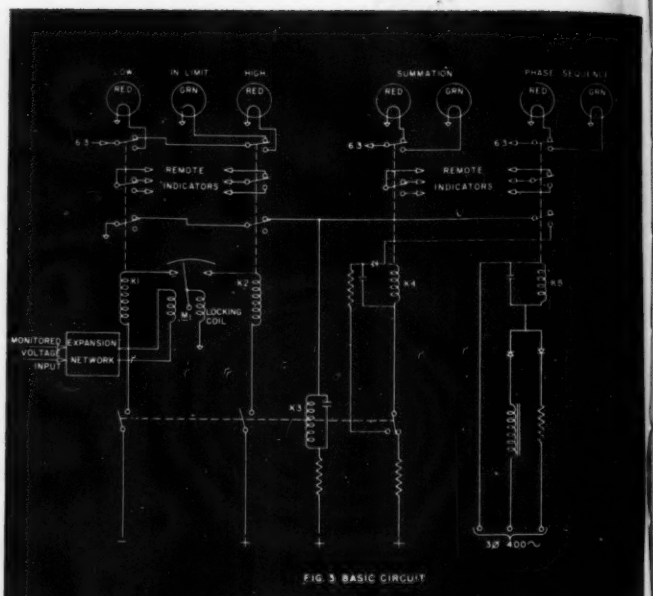


**Fig. 2 In a typical indicator circuit with the meter MI reading within limits, interrupter relay K3 is closed. If phase sequence is correct, phase sequence relay K5 and summation relay K4 are also closed. Green "In Limits," "Summation," and "Phase Sequence" amps are illuminated. Should the monitored voltage exceed low or high limits, load relays K1 or K2 will close, activating the associated red warning amp and also breaking the ground return circuit for K3 and K4. The opening of the interupter relay, K3, is delayed by its parallel capacitor for approximately one second. When K3 opens, the supply voltage to relays K1, K2 and K4 is removed, permitting the closed load relay to open. At the same time, the locking coil circuit opens, allowing the meter to sample the monitored voltage. Opening of the closed load relay restores the ground return to relays K3 and K4. After a brief charging period, relay K3 closes, restoring voltage to the load relays and summation relay. If the monitored voltage is still out of limits, the appropriate load relay will again close and the entire cycle will repeat. The action will continue with the appropriate red and green lamps flashing alternately until the monitored voltage returns within limits and relay K3 closes.**

**Relay K4 operates the summation indicators, powering a red summation lamp when open. This relay also has a charging circuit consisting of a large capacitor, a diode and a resistor. The charging rate and relay closing time is determined by a series resistor and the capacitor shunting the relay coil. The diode in series with the capacitor permits charging current to flow into the capacitor, but prevents the capacitor from discharging through the relay. Summation relay K4 therefore responds instantly, opening and giving a red summation warning when its ground return is broken by the closing of any meter load relay. Since the capacitor across K4 cannot discharge through the diode, a separate discharge path must be provided. This is accomplished by another set of contacts on the interrupter relay K3. When relay K3 is closed, it supplies operating current to summation relay K4. When K3 opens, it discharges the capacitor through a low value of resistance. The longer closing time required by K4 prohibits it from pulsing along with K3, and the green summation lamp will not illuminate until approximately two seconds after K3 stops pulsing, i.e., after all monitored voltages have returned to "In Limits."**

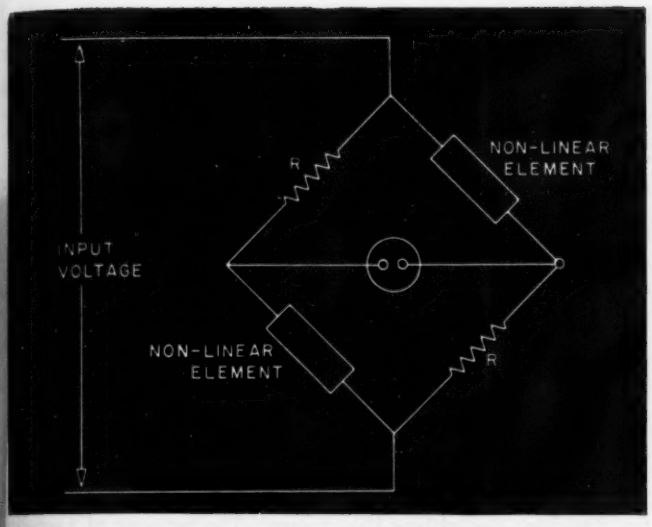


**Fig. 3 The meter scales are expanded to cover the desired range by employing a non-linear bridge. Monitored voltage drives the bridge, which in its simplest form contains two linear and two non-linear arms.**

arms connected across the 3-phase voltage lines. One of the resistive arms includes a relay, and arm values are selected to close the relay when phase sequence is correct, and open it (or keep it open) when phase sequence is incorrect. The phase sequence relay (K5) operates a red or green lamp in the same manner as the summation relay, and has a set of normally open contacts in series with the voltage supply to K4. Therefore, in order for the summation relay to close and show a green light the phase sequence must be correct and all monitored voltages within limits.

All meter load relays as well as summation and phase sequence relays, have an extra set of single-pole double-throw contacts which are wired to receptacles in the rear of the chassis. These contacts are completely isolated from the other chassis circuits, and may be used to control external indicator lamps, relays or other devices. For ease of maintenance, plug-in components are used wherever practical.

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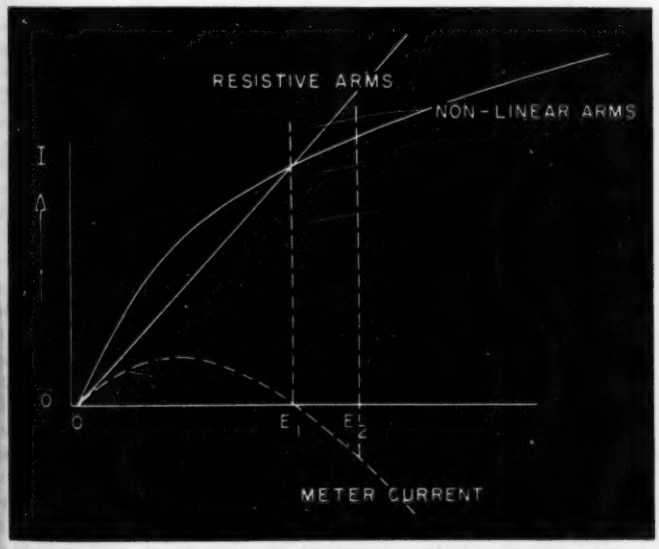


**Fig. 4 EI plot of the bridge arms shows that at some voltage $E_1$, current through the linear and non-linear elements will be equal and the meter shows no deflection. An increase in applied voltage unbalances the bridge and deflects the meter until full scale deflection occurs at $E_2$. Full scale meter range then becomes $E_1$ to $E_2$. Selection of components determines the expanded scale range. In the Titan monitor, the d-c meter scale is expanded across a 22-to 34-volt range, and the a-c meter across 110 to 120 volts.**


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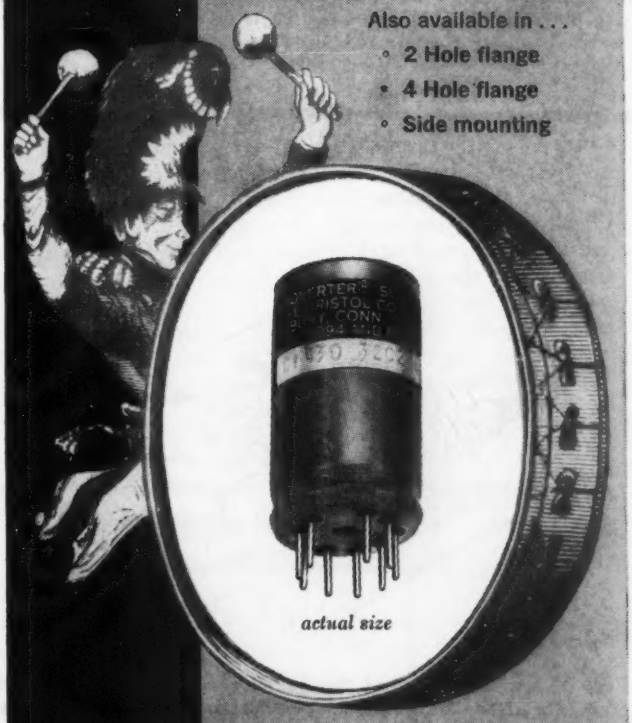

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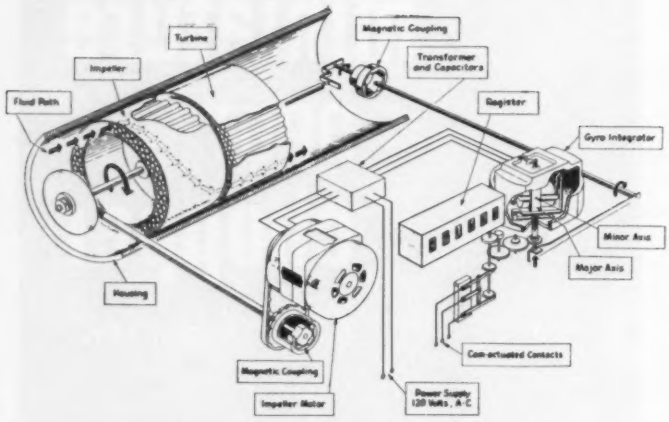


**Fig. 1 Flow-rate sensor consists of an impeller and a stationary turbine. The impeller is driven through a magnetic coupling at a constant speed by the synchronous motor. As the fluid enters the instrument, the rotating impeller gives it an angular momentum or twist. The fixed turbine removes this momentum and in doing so receives a torque proportional to the mass rate of flow. Magnetically coupled linkage transmits this torque to the gyro-integrating mechanism where it is applied around the minor axis of the gyroscope causing the gyro to rotate about its major axis at a rate proportional to the torque and thus to the mass rate of fluid flow. This rotation is transferred through a gear train to the cyclometer register where the mass flow is totalized and indicated in pounds.**

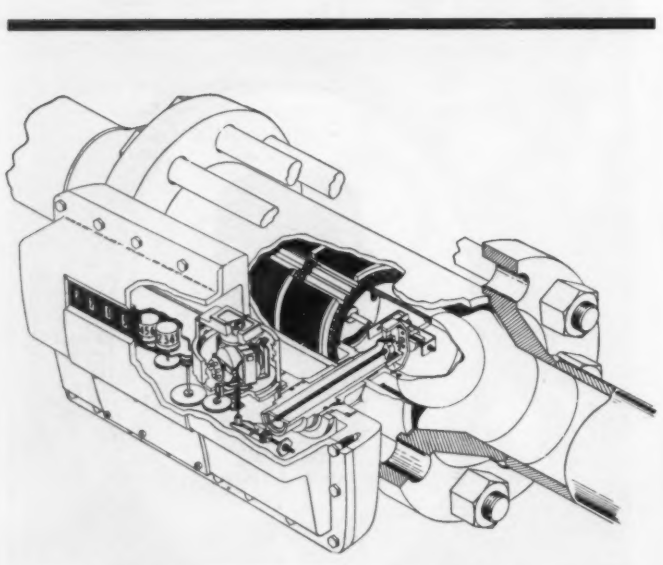

**Fig. 2 Cutaway view of the G. E. mass flowmeter showing elements of the flow-rate sensor, magnetic coupling between fixed turbine and integrating mechanism, and the gyro integrator to the cyclometer register. The gear train output actuates a contact device which can be used to make or break an electrical circuit. The electrical pulses can be used to actuate various auxiliary equipment such as ticket printers, registers, etc. at remote locations. The gyro motor and impeller motor run synchronously and operate from a common power supply. Thus nominal line-frequency fluctuations (plus or minus five percent) will affect their speed in exactly the same proportion and the gyro precession rate will still be in exact proportion to the mass flow rate.**

## "TRUE MASS" FLOWMETER

## MEASURES FLUIDS IN POUNDS

The long search for a practical industrial instrument to directly measure liquid and gas flow in pounds has resulted in development of a "true mass" flowmeter, according to a joint announcement by General Electric and Black, Sivalls and Bryson, Inc. The simple, low-maintenance device precisely measures the weight of flowing fluids with high accuracy over wide ranges of flow rate, pressure, temperature, and density without additional measurements and corrections for these variables. The new instrument incorporates several basic contributions to flowmeter technology. One is a small gyroscope which directly and automatically totalizes flow in a novel manner. Another is a flow-rate sensor, consisting of a constant-speed impeller and a stationary turbine arranged for axial flow.

The impeller gives a twist to the fluid stream and the fixed turbine straightens the stream. The amount of torque exerted on the turbine when removing the twist is proportional to the mass rate of flow. The gyro integrates this torque with respect to time, and the output is continuously summed up on a cyclometer dial in pounds. A marked advantage of this sensing and integrating system, is its ability to operate from an unregulated power supply without any measurable effect on meter accuracy.

First production units of the General Electric instrument —expected to be available early in 1960—will meter many industrial fluids including naptha, gasoline and other hydrocarbon liquids, refinery and natural gas, oxygen, and nitrogen, and liquefied hydrocarbon gases.

Pointing up the significance of the new device, Mr. Parker, General Manager of General Electric's Instrument Dept., noted that the pound is a fundamental fluid measurement unit used by many industries as a basis for figuring costs, regulating blending operations, measuring yields, determining energy or BTU content, or metering bulk loading operations. However, up to now, commonly used methods of determining fluid flow by mass have first required a measurement of fluid volume which must be manually or automatically corrected for such variables as fluid temperature, pressure and density to determine pounds.

Manual methods are cumbersome, time consuming and leave room for human error; automatic correction systems are relatively complex and present additional maintenance problems.

In contrast, Mr. Parker explained, the General Electric flowmeter—sensing mass directly—requires no in-between calculations, is completely self-contained weighing about 100 lbs., and is designed for long, maintenance-free operation. This inherent simplicity and the high accuracy (plus or minus one percent of reading) of the flowmeter under changing conditions, Mr. Parker noted, make the instrument ideal for those applications where fluids are or should be measured by weight.

The flowmeter is also compatible with automation, since it emits a series of electrical pulses, each representing a given weight of fluid. This signal can be used to operate auxiliary equipment such as remote counters, printers, and totalizers.

Looking beyond present applications, Mr. Parker indicated G.E. is continuing development work to adapt the basic flowmeter to measurement of other gases and liquids. These are expected to include light gases such as hydrogen and helium as well as high-temperature, corrosive and cryogenic fluids—steam, acids and liquid oxygen.

Black, Sivalls and Bryson, Inc. of Kansas City, Missouri, will market the flowmeter in the natural gas industry. They cooperated with G. E. in the development of the meter and handled its proving out for measurement of natural gas.

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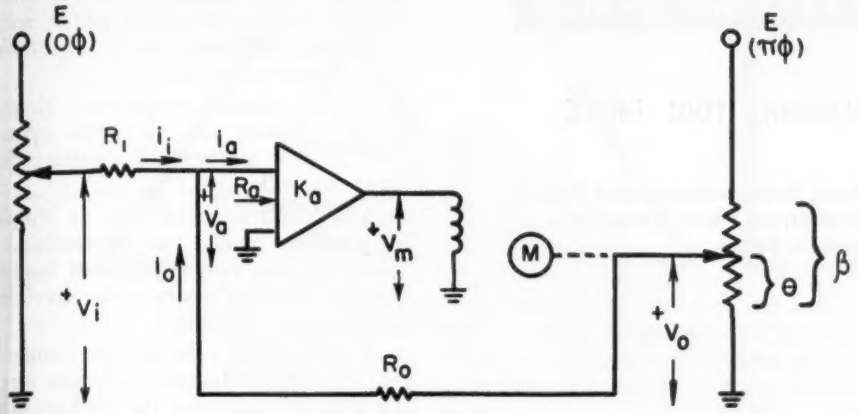



Fig 1(a) Parallel Summation

## CURRENT NULLING SERVOS

### Parallel Summation in Servo Computer Circuits

Parallel summation circuits offer some unique and highly desirable characteristics for servo computer applications. James W. Berkovec of John Oster Manufacturing Co. recommends use of these circuits to supplement the characteristics of voltage nulling servos and points out their advantages. Fig. 1(a) shows the use of parallel summation in a simple potentiometer-type repeater. The Thevenin's theorem equivalent circuit of Fig. 1(b) suggests the basis for simple calculations. Fig. 2 extends the application of parallel summation to the case of multiple inputs and follow-ups.

The basic null condition occurs when the sum of all currents (input and feedback) at the amplifier input point equals zero. In Fig. 1(a), for example, at null,

$$V_i/R_i = V_o/R_o$$

Obviously, the overall gain and the individual input and output scale factors depend upon the values of the summation resistors. For maximum power gain where a transistor or magnetic amplifier requires a finite power input, a transformer may be used to match equivalent source resistance at the summing point $R_oR_i/(R_o + R_i)$ in Fig. 1(b) to the amplifier input impedance.

A variety of interesting functional relationships are conveniently generated in parallel summation servos:

1. The individual input summary resistors may be replaced by potentiometers to provide special input functions.
2. Nonlinear potentiometers may be installed in one or more of the shaft-driven output circuits to provide a variety of nonlinear functions readily adjustable by changing the summation resistors.
3. Slight nonlinearities may be generated by parallel summation of the outputs of a linear and a nonlinear potentiometer through appropriate resistors.

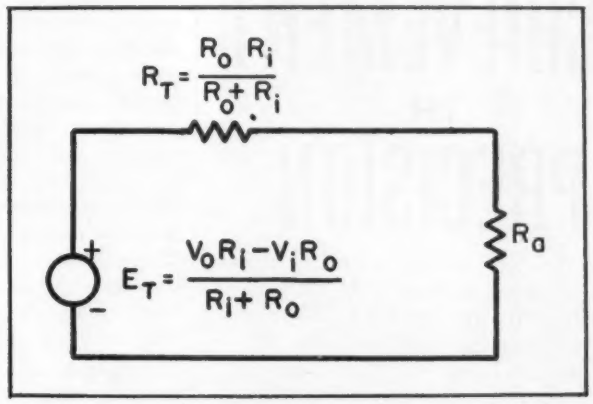



Fig 1(b) Equivalent Circuit Parallel Summation Servo

4. A complex nonlinear function may be generated by dividing up the function among several follow-up potentiometers.

Errors in parallel summation circuits depend directly upon the accuracy of the summing resistors. It is sometimes difficult in high-impedance circuits to find resistors of sufficient accuracy and stability over a wide range of ambient conditions. The output impedance of the potentiometer, which varies with the shaft position, must be considered as part of the summing resistor circuitry.

On the other hand, parallel summation provides flexibility, the convenience of a common ground, simple scaling adjustment, and adaptability to many variables.

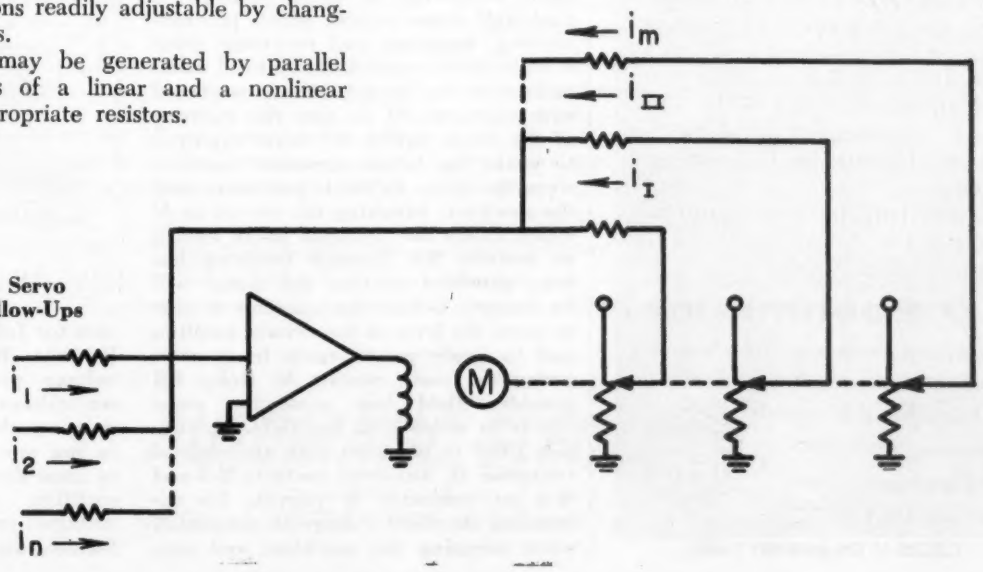
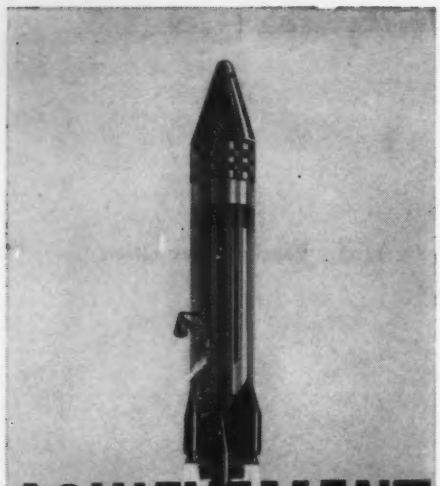



Fig 2 Parallel Summation Servo with Multiple Inputs and Follow-Ups



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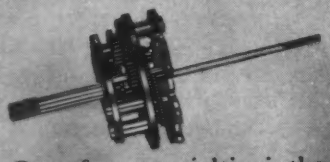

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SYSTEMS DESIGN

## MACHINE TOOL DRIVE

### Auto transformers and Silicon Rectifiers Form Variable Speed Drive

Lathes for tool and gage makers demand a variable speed power source for the spindle that provides an easily adjustable range of speed for the minimum transmission equipment. Among the variety of variable speed drives now available are variable pitch sheaves, hydraulic motors, regulated eddy-current clutches, wound rotor motors and d-c shunt motors. Of these, d-c shunt motors operating from a variable voltage source for the armature and with shunt field control offer the most advantages. W. A. Means of Barber-Colman in Rockford, Illinois, discussed the advantages and disadvantages of some of these drives at Westinghouse's 23rd Annal Machine Tool Electrification Forum. Here's his description of Barber-Colman's solution to the problem by combining variable autotransformers and silicon rectifiers.

The basic requirements for the drive were:

- The drive should have a 3hp rating with a maximum of horsepower over as wide a range as possible.
- The drive should be a combined control using a d-c shunt motor, with field and armature control adjustable from a common shaft.
- Power supply components should be of sufficient size to permit operation at 200 percent of capacity for short intervals.
- The control should be as simple as possible, involve no electronic devices and use only equipment that is familiar to, and easily understood by maintenance personnel.
- The control should be rugged enough for production toolroom service while maintaining the performance required in precision tool and gage making.

A combination of variable autotransformers and silicon rectifiers was selected because it serves as a very simple d-c voltage source. Over the past few years the development of semiconductor rectifiers has been very rapid and their high efficiency, small size and decreased cost have made them an attractive means for d-c rectification.

Variable voltage for speed control requires a means of varying the a-c voltage in addition to silicon rectifiers. After use in electrical laboratories for fifteen or twenty years, variable autotransformers now have been improved sufficiently to withstand industrial service. They serve as a rugged, simple variable a-c source. Thus, by combination of these two devices, Barber-Colman engineers obtained a very simple and efficient power supply;

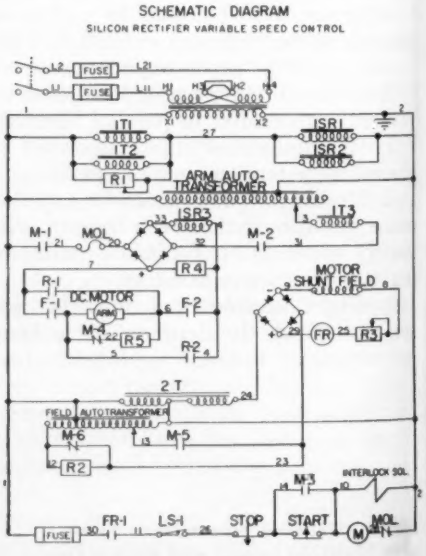


**Fig 1 Addition of transformer, 2T, limits the minimum field voltage. Resistor R3, added in series with the field, provides adjustment at maximum speed, eliminating the need for an adjustable mechanical stop on the rotation of the autotransformer. Starting and stopping the machine is accomplished by switching the a-c input to the armature rectifier. Reversing is done through a push-pull drum switch, which provides starting, stopping and reversing from a single lever control. Mechanical interlocking of the drum switch is combined with contactor *M* so that the contacts of the drum switch are never required to make or break armature current, since the drum switch is pushed to stop the machine, breaking the circuit to *M* which closes the dynamic break circuit on resistor R5. Enough breaking has been provided so that the motor will be stopped before the operator is able to move the lever to the reverse position and to apply power again by re-energizing the main contact *M*. Relay FR provides field loss protection since coil is in series with the field. Its contact FR-1 is in series with the coil of contactor *M*. Auxiliary contacts M-5 and M-6 on contactor *M* provide for increasing the field voltage to maximum when stopping the machine, and provide for full field voltage when starting. Resistor R-4 limits the regenerated voltage produced when the field is strengthened rapidly, by rapidly decreasing the control from high speed to low speed. It also serves as a load to limit the impedance of the armature rectifier, suppressing any transient voltages produced by switching transformers on the supply lines.**

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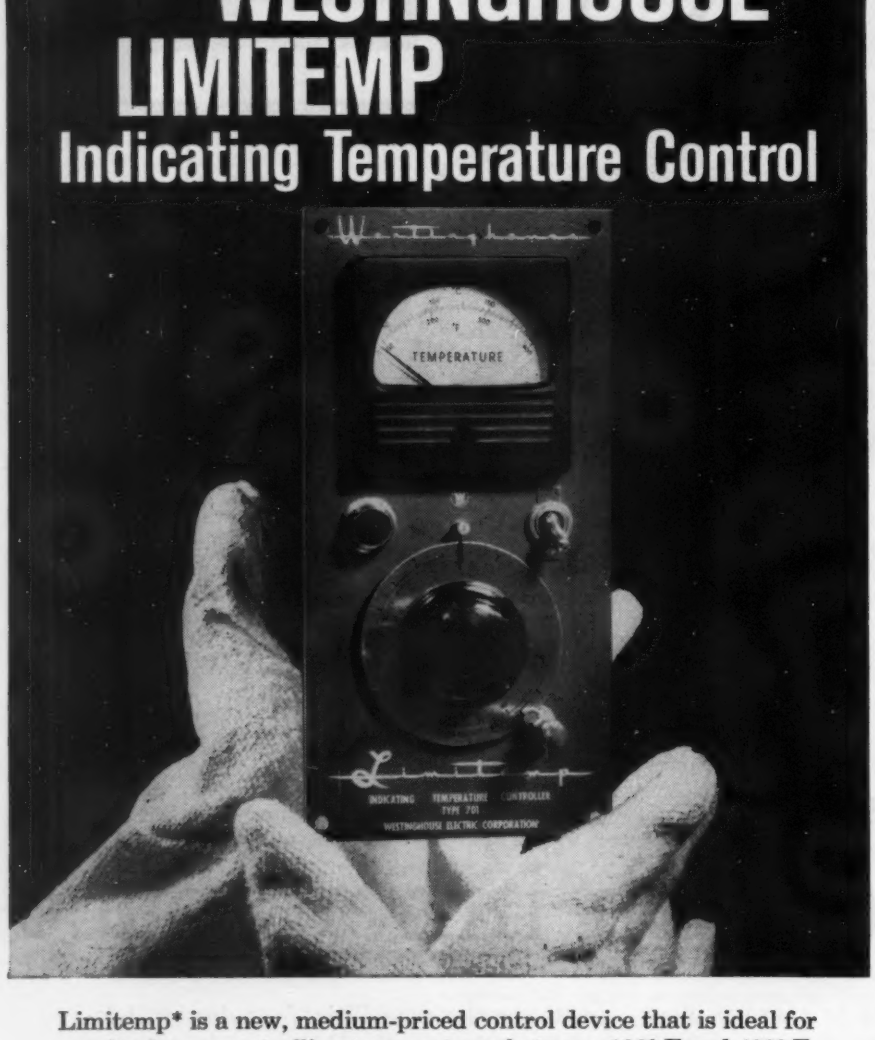
## Indicating Temperature Control

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COMPACT: 4 in. wide, 8½ in. high, 6 in. deep

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good regulation was achieved by the inherently good regulation of the autotransformer and the low forward-voltage drop of the silicon rectifier.

To achieve good regulation of a d-c motor, it is necessary to compenste in some manner for its IR drop. The method devised to accomplish this was to add an additional a-c voltage to the a-c voltage supplied to the rectifier from the variable autotransformer. This was found to be feasible as the compensation voltage required was only 15 to 20 percent of the rated armature voltage. Correspondingly, the power requirements of the compensating circuit components are also 15 to 20 percent of the rated capacity of the drive.

Figure 1 is a schematic of the drive which uses a 650-rpm, 120-volt, d-c shunt motor, controlled from 2600 rpm to 650 rpm by field control, and from 650 rpm to 65 rpm by armature control. The supply is single phase, with a main power transformer provided to transform the line voltage to the 120 volts required. This 120 volts is supplied to the armature autotransformer. Output of the autotransformer is added to the voltage supplied by the sec-

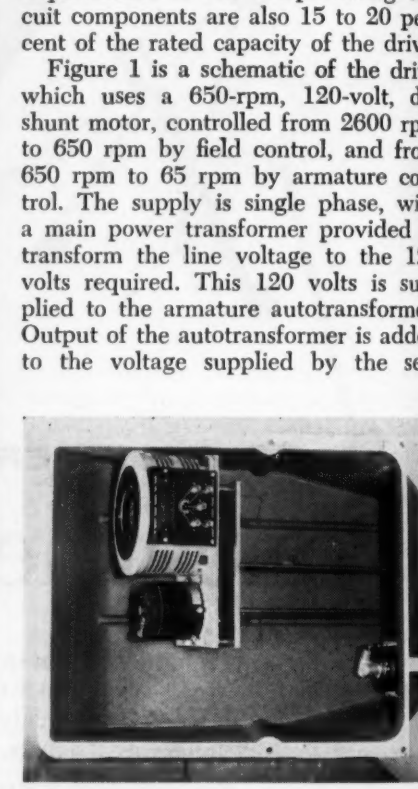

**Fig 2 A requirement for the drive was that the control be easily adjusted from a knob operating a common shaft. Operation of the two autotransformers requires some mechanical couplings if full rotation of both is to be used. The two must also operate in the proper sequence. Starting at low speed, the armature autotransformer variable tap is turned through its complete rotation until the maximum armature voltage is reached and the motor is operating at base speed. At this point, the field autotransformer tap is rotated to decrease the field voltage until the end of its rotation is reached and the motor is operating at maximum speed. An auxiliary gear provides a multiple number of revolutions of the adjusting knob. This allows the operator to make small speed adjustments which would be difficult if the total adjustment were crowded into less than one revolution.**

ondary winding of transformer 1T3 and then fed to the a-c input of the armature rectifier. This voltage is rectified and supplied to the armature of the motor; the voltage of the transformer 1T3 is determined by the voltage on its primary windings, 1T1 and 1T2, which are in series with the saturable reactor windings, 1SR1 and 1SR2. Voltage on the primary windings, 1T1 and 1T2, will be dependent upon the impedance of the reactor windings 1SR1 and 1SR2. With no current in its control winding, 1SR3, the impedance of 1SR1 and 1SR2 is high. Therefore, most of the line voltage will appear on the reactor windings, 1SR1 and 1SR2, and only a small part on the compensating transformer 1T1 and 1T2.

Thus, when operating at light loads the motor will be supplied with the rectified voltage of the output of the autotransformer. As the loading on the motor increases and the increased armature current flows through the reactor control windings 1SR3, the impedance of the reactors 1SR1 and 1SR2 is decreased, causing the voltage across the transformer 1T1 and 1T2 to increase. The increase in voltage on the transformer windings 1T1 and 1T2 increases the voltage on its secondary 1T3. This produces an increase in the a-c voltage supplied to the armature rectifier, and consequently, an increase of voltage to the armature of the motor. This increase in voltage to the armature with increase in load can be made to compensate for the IR drop of the motor, thereby maintaining almost constant speed as the load is varied.

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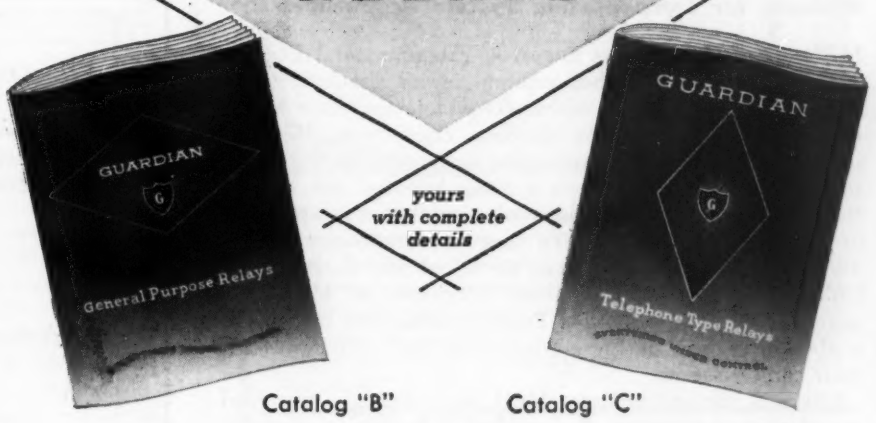


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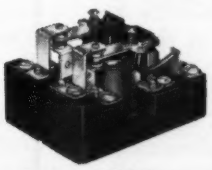

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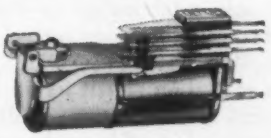

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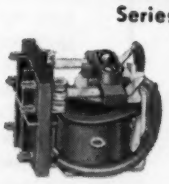

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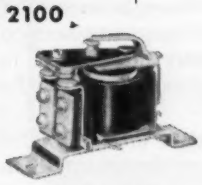

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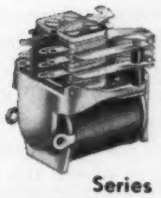

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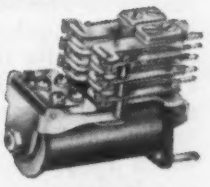

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NEW TECHNIQUES

# Random Motion Test Techniques

### Methods for Compensating System Resonances

In Part 1 of Components Digest 4, Environmental Testing, March 1959, we described equipment for simulating random and complex wave vibrations which constitute severe environments for reliable airborne equipment. We also pointed out that compensating for resonances in the vibration exciter and specimen is a major problem not only in the design of the simulation equipment but also as factors in the testing procedures. To give test engineers a fuller understanding of this problem we asked Mr. G. B. Booth, Chief Electronics Development Engineer of MB Electronics, Inc., a subsidiary of Textron Industries, Inc. to describe the nature of these resonances and techniques for their compensation.

Given a varying voltage signal representing a specified complex wave vibration, the problem is to drive a vibration exciter and specimen to follow the specified motion. If power amplifiers are used directly to drive the exciter, gain of the system (ratio of table and specimen acceleration to input voltage) varies greatly with frequency. The theoretical acceleration response of a random motion test system in Fig. 1 shows that nowhere is the gain constant through any range of frequency. Equalizers are required to obtain a flat response. Adjusting the gain of the equalizers to the inverse of the vibration exciter results in a constant system gain.

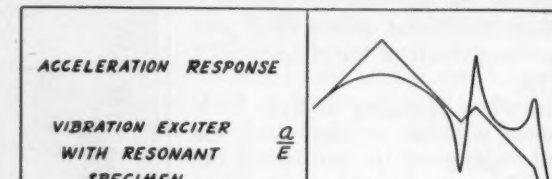
#### PRESENT EQUALIZATION TECHNIQUE

The block diagram on Fig. 2 shows the basic elements in a complete random-motion vibration testing system using the present method of equalization. The upper part of the system produces the desired excitation signal. The following elements of the system reproduce a table motion with predictable relationship to the input signal. Monitor circuits finally indicate or record the performance of the random-motion system.

The excitation signal is fed into one or more peak-notch equalizers in series, one equalizer for each peak and notch combination caused by a specimen resonance. Following the peak-notch equalizers, the signal passes through an exciter equalizer comprising two sections. A mid-frequency section compensates for the lower broad-band resonance at "$\alpha$" in Fig. 1 and a high-frequency section compensates for the sharp axial resonance at "$\beta$" in Fig. 1.

The equalized signal then goes through a low-pass filter which limits frequency to the equalization range and then to a displacement limiter where the signal is limited so that the table displacement cannot exceed the design limits of the vibration exciter. Any errors in adjusting previous signal-determining circuits will not damage the equipment.

It is convenient to place by-pass switches on all the circuit elements preceding the displacement limiter, so that each element of the signal-determining network can be adjusted and placed into the operating system in sequence. A number of signals—up to 120—can be drawn from various points in the random-motion system and fed to a signal monitor where required information is supplied to the various pieces of output instrumentation.




$$\frac{a}{E} = j\omega K \frac{1}{1-\left(\frac{\omega}{\alpha}\right)^2+2j\zeta\frac{\omega}{\alpha}} \times \frac{1}{1-\left(\frac{\omega}{\beta}\right)^2+2j\zeta\frac{\omega}{\beta}} \times \frac{1-\left(\frac{\omega}{N}\right)^2+2j\zeta\frac{\omega}{N}}{1-\left(\frac{\omega}{P}\right)^2+2j\zeta\frac{\omega}{P}}$$

MID FREQ HIGH FREQ PEAK-NOTCH

**Fig 1 The theoretical acceleration response of a vibration exciter with a resonant specimen. An adjacent notch and peak, representing a single specimen resonance, appears at frequencies "N" and "P". Equality between the inductive impedance of the driver coil and capacitive impedance of the table result in a resonant peak at the frequency "α". The frequency "β" is the axial resonance in the high-frequency range. An increase in effective mass at the point "N" produces an abrupt reduction in acceleration and a sharp notch in the frequency characteristic. Above the point "P", the specimen mass becomes isolated from the table and an increase in acceleration level results exactly as if the table were unloaded. The expression below the graph gives the acceleration-voltage ratio as a function of frequency "ω". The first two terms represent the response of the exciter in the mid-frequency and high-frequency ranges, while the last term represents a peak-notch resonance response due to reflected forces developed by the specimen. Since these factors are independent multipliers, we can add to the expression as many peak-notch factors as are necessary to account for all degrees of freedom in the specimen. The resonances which occur do not represent poor design but are simply unavoidable phenomena in both the exciter and specimen which must be overcome in equalizing a random-motion vibration testing system.**

The three curves in Fig 3 were taken from actual tracings in tests on a specimen. The topmost curve is the entirely unequalized acceleration-voltage ratio as a function of frequency up to 2000 cps. In addition to mid-frequency resonance at about 120 cps and high-frequency resonance at 2000 cps, there are three sharp specimen resonances at

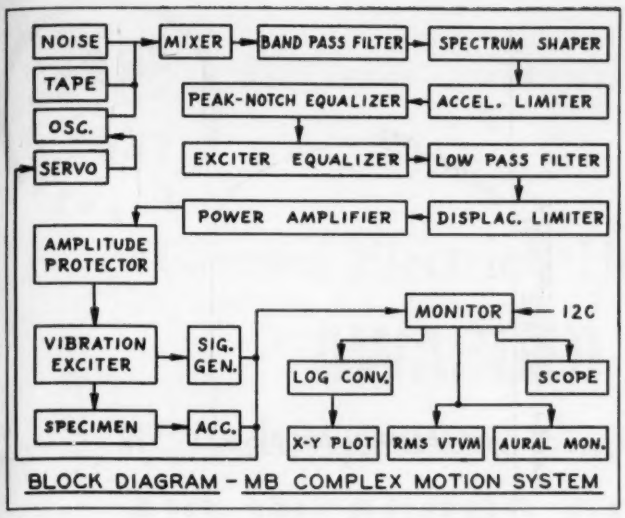



**Figure 2**

740, 1200, and 1600 cps. A 2000 cps low-pass filter restricts the frequency range.

With the peak-notch equalizers inoperative, the center curve in Fig 3 shows the vibration in the acceleration-voltage ratio when the exciter resonances have been fully equalized. The nature of the specimen resonances have not been affected. In the lowest of the three curves in Fig 3, the two exciter resonances and three specimen resonances have been equalized. Three separate peak-notch equalizers have been adjusted to eliminate the effect of specimen resonances on the exciter response. Although some residual effect of resonance still remains, the response varies less than 3 db or about ±15 per cent as compared to an original range of about 300 to 1.

Since mid-frequency and high-frequency resonances are produced by independent phenomena, equalization of each in the exciter equalizer must also be independent. The curves in Fig 4 are actual tracings of the equalizer characteristic in "db" as a function of frequency for five different settings of the mid-frequency control. For this demonstration the high-frequency control is constant with a notch at about 2000 cps and the damping controls are fixed. Continuous adjustment of the mid-frequency control while observing the output signal at the exciter table can attain an optimum setting that closely matches the shape of the mid-frequency peak. The equalizing curves show very much the same affect on exciter response as a varying table mass.

Similarly, the response of the high-frequency section of an exciter equalizer is given in Fig 5 for a constant setting of the mid-frequency control. The equalizing notch can be shifted continuously to match the peak of axial resonance. Passing the unequalized signal through the equalizing circuits of Fig 4 and Fig 5—each represented by respective multiplying factors in the expression in Fig 1—will produce the required equalized characteristic after proper adjustment of the mid-frequency and high-frequency control. It is evident that the over-all frequency response is essentially constant.

The response of a particular peak-notch equalizer to changes in the notch frequency control is shown in Fig 6, in which the damping controls are fixed. This control varies the notch frequency, the ratio of peak to notch gain, and the mass offset in the manner described by the last term of the equation in Fig 1.

To further illustrate the equalization function, Fig 7 shows the response with the peak and notch damping controls simulatenously adjusted without varying the peak or notch frequency controls. The response is as would be predicted by a variation of the damping factors "$\zeta_N$" and "$\zeta_P$" in the equation of Fig 1.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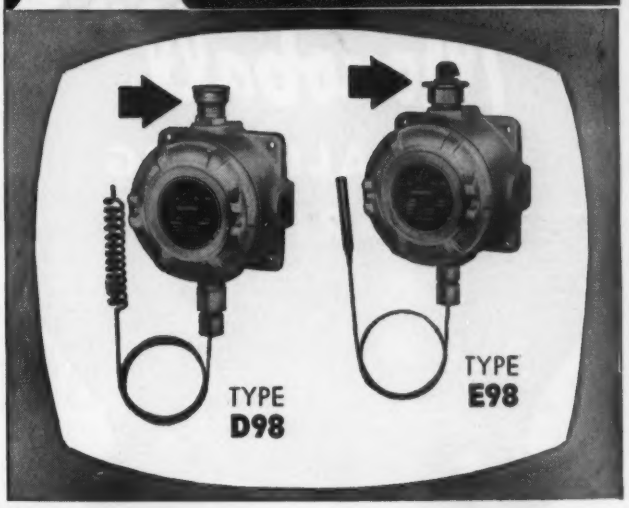


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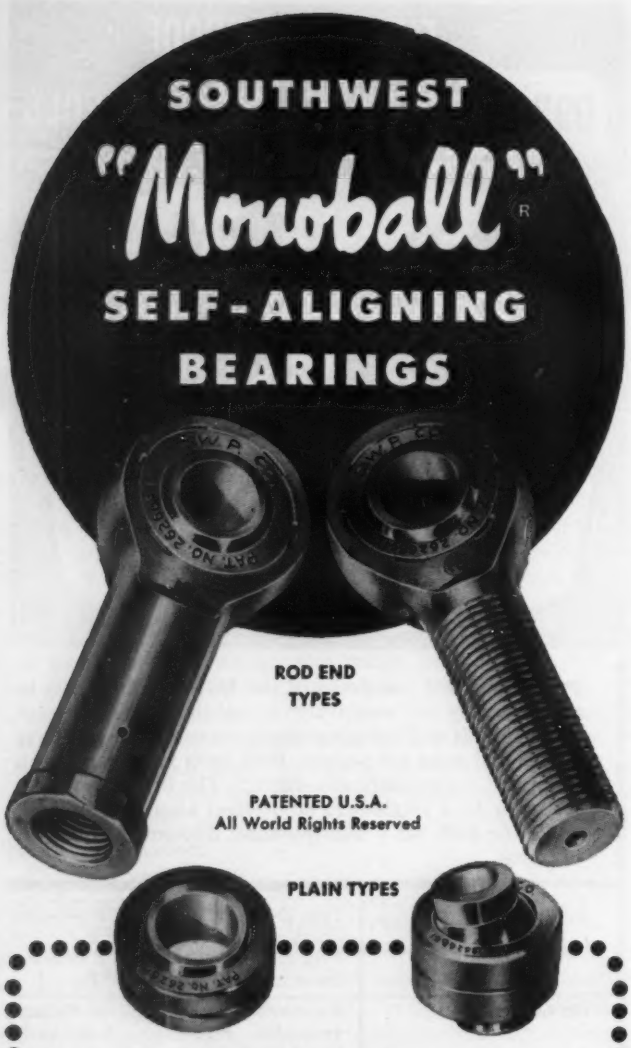


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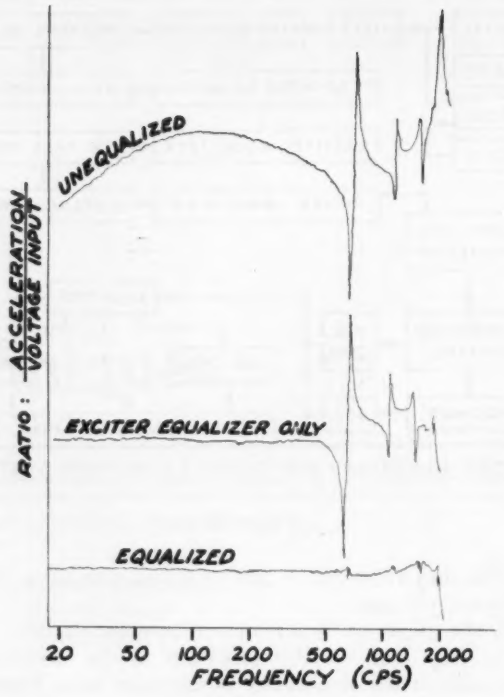


**Figure 3**

### EQUALIZER ADJUSTMENT

To adjust the equalizers, the amplifier and vibration exciter are turned off and the output is fed through the equalizers and conversion circuits to an X-Y plotter. The exciter and specimen resonances are equalized by adjusting the equalizing controls until the motion of the X-Y plotter pen, lifted from the paper, now plotting equalizer response only, follows the original trace for the actual acceleration-voltage ratio of the unequalized exciter system. As soon as the controls are adjusted so that the pen follows the line, the equalization process is complete. If the equalizers are now connected in series with the exciter in the normal manner of Fig 2, the equalized response of Fig 3 is obtained.

The limiters, spectrum shaping, and signal inputs are adjusted and the level raised to that specified for the test.

### NEW EQUALIZATION TECHNIQUE

The block diagram of Fig. 8 illustrates the new equalizat'on technique, called random band equalization, in generalized form. The blocks at the upper left represent noise bands of adjacent frequencies. Each of these blocks is followed by an adjustable attenuator. Outputs of the many attenuators are added in a power amplifier which feeds the vibration exciter and specimen. The resulting acceleration of the exciter and specimen is fed to the analyzer. Filters at the input of the analyzer correspond to the original noise bands. Output of these filters is sequentially selected by a commutator and presented on a monitor. A common monitor might be an oscilloscope screen with frequency along the horizontal axis and acceleration density in the vertical direction. On this screen would appear a series of dots representing the magnitude of the acceleration density for the various analysis or generate bands. To equalize the system, the operator adjusts the attenuator corresponding to each dot to obtain the desired level.

This new technique has advantages over the one now in use. It is also possible to monitor the results of a test while the test is proceeding and to modify the level to take care of changes in the system that occur during the test.

The system presents problems, however. The analysis bands must be narrow. If they are wide, the operator cannot equalize for normal resonances. For example, if a speci-

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Systems-oriented engineers and scientists will appreciate the broadband technical challenge of the Air Weapons Control System 212L. There are important openings for men who are experienced in: Weapons Systems Analysis • Mathematical Analysis of Engineering Problems • Computer Programming • Military Communication Systems • Radar Systems • Weapons Control Systems • Electronic Circuitry • Industrial & Military Psychology.

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**VERSATILE AIR CONTROL APPLICATIONS** The revolutionary 212L can be used to defend a single airfield, or, by linking control sites together, it could be used in a limited action to provide air control for an area the size of Alaska. Similarly, by linking the capabilities of countries together, a system could be provided for the air control of an entire continent. Designed for *both* fixed and mobile applications, the 212L will be used primarily outside the U. S. since the SAGE system is used for the defense of this country.

**HMED IS ALSO DESIGNING THE "HEART" OF THE SYSTEM** In addition to its prime mission of providing systems management, HMED will design, develop and produce the data processing and display subsystem which is the "heart" of the 212L. Capable of rapidly and automatically detecting and tracking air targets, the subsystem operates without human assistance, except under unusual circumstances.

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- Missile Guidance
- Data Handling Systems
- Communications

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**HEAVY MILITARY ELECTRONICS DEPARTMENT**

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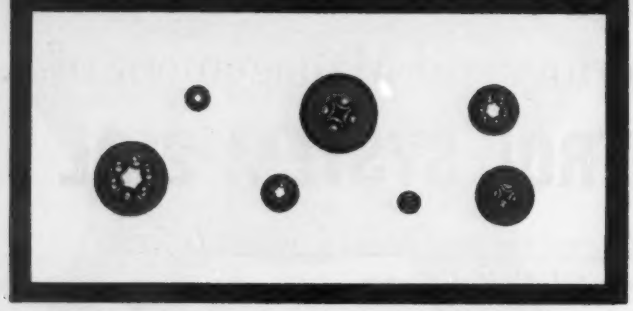

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COHRlastic FSR is a new and unique silicone rubber product. The unusual and random orientation of silicone fibers provides many useful properties superior to silicone sponge and foam. It should be extremely suitable for many applications including shock and vibration isolators, cushions, thermal insulators, high temperature press pads, pressure moldings, etc. COHRlastic FSR is being introduced in sheets 1/4" thick, 9" wide, 6' long, and in a density of 20 lbs./cu. ft. As applications develop, COHRlastic FSR will be made in continuous lengths, larger widths, different thicknesses and various densities in the range of 15-25 lbs./cu. ft.

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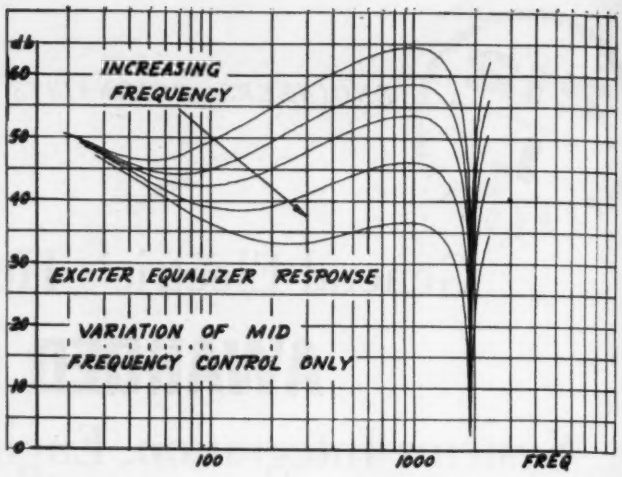
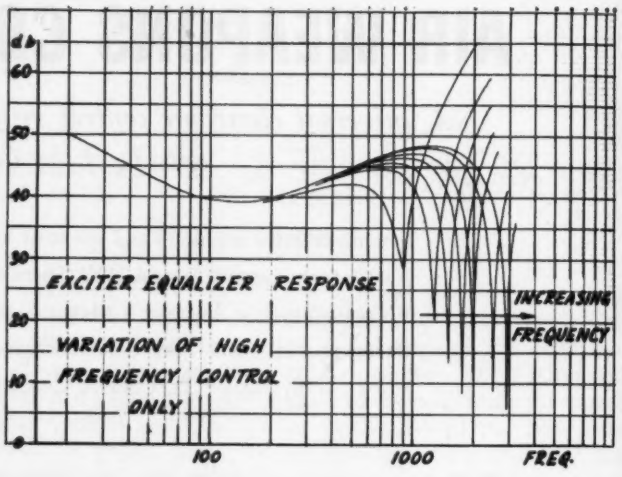
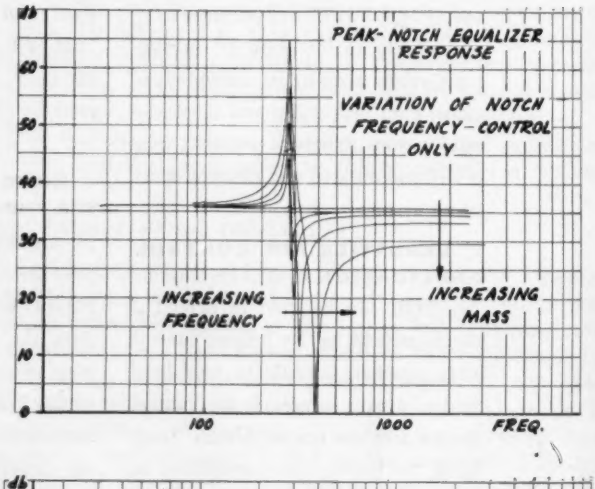
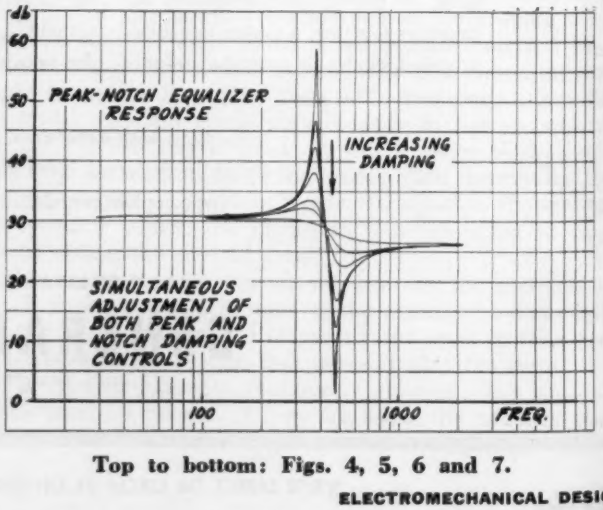



Top to bottom: Figs. 4, 5, 6 and 7.

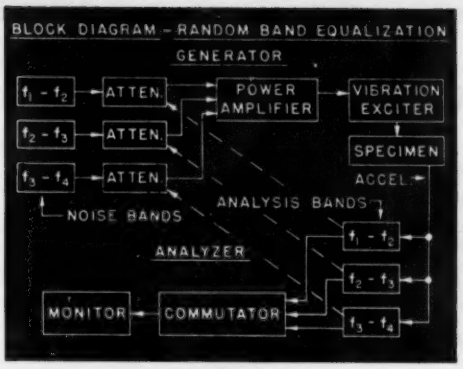



**Figure 8**

men has a Q of 50 @ 500 cps with 12 percent of the mass being decoupled from the table the peak to notch ratio is 30 db and the peak frequency would be 530 cps. Since both the peak and the notch would fall within a single band the operator would be unable to reduce the spread in equalization. In addition, the operator would be fooled since the monitor would obscure the deficiencies of the equalization method. He would see a spot position representing the average value of the entire band and would not realize that portions of it were lower and others higher in value.

If the bands are narrow the system can be designed to overcome the above deficiencies. But how narrow should the band be to be satisfactory? If the specification requires a ±3 db equalization then for the same example (a Q of 50 @ 500 cps with a mass isolation of 12 percent and 30 db spread in 30 cps) since we need to reduce the magnitude of each discontinuity to 6 db, we would need 5 filters with bandwidth of 6 cps each. A plus or minus 3 db equalization would thus require 330 bands. Frequently laboratories can accept a plus or minus 5 db tolerance. If we use this specification for our example we need only 3 filters with a bandwidth of 10 cps each. In this case 200 bands would be required. Although this is just an example, its implications are fairly typical. If a Q of 50 is assumed to occur, and this has been demonstrated in practice, a bandwidth of 10 cps will restrict the peak to notch ratio to a plus or minus 5 db almost independently of the mass being isolated.

This requirement of at least 200 bands presents the major problem of the new technique. The 200 knobs are difficult to adjust and the various filters should be sharp if the adjustments of the knobs are to be independent. In addition, the response of the monitor would be sluggish. For example, if 10 cps bandwidths are used the response time must be in excess of 3 seconds if the wiggle of the spot is to be held to total spread of 2 db, which approaches the tolerance on the band. This means that three seconds would elapse between the time the operator tries to readjust the attenuator and the time that the spot moves 60 percent of the way to the new position. If four adjustments per attenuator are required and the time per band is about ½ minute, and if adjustment of all 200 bands are required, total adjustment time would be 1½ hrs.

This problem can be solved by making adjustment of the attenuators automatic. This could be done by comparing the output of each analysis filter with the desired value for that band and using the error to actuate a servo to rotate the desired attenuator. For 10 cps bandwidths 200 such servos could simultaneously adjust all of the attenuators in a few minutes. Minor problems that might arise due to the action of more than one servo on a single resonance can undoubtedly be solved. The cost could be reduced by using fewer servos successively, but this would increase the time required for equalization.

Circle No. 102 on Inquiry Card

### 3 New Relays

Hi-G, Inc., who early this year moved into their new building comprising 22,000 ft. of air-conditioned area ideally suited to manufacture of precision relays, recently announced availability of 3 new relays:

1) ESS series hermetically sealed relay developed to meet vibration of 20G to 2,000 cps with a sensitivity of 80 mw in a 2 PDT unit. Coil resistances as high as 36,000 ohms are available. Contacts are rated at 2 amperes resistive for life of 100,000 cycles. Relay enclosure is approximately 1" square and 1½" high. Suitable for use at ambient temperatures up to +125C. 2) Double-ended 4 pole double throw relay approximately ⅝" diameter which may be used as an in-cable assembly, with coil leads connected, both ends internally. Uses two parallel, magnetically isolated structures and one common coil. Suitable for use under vibration of 20G to 2,000 cps. Contacts rated at 2 amperes resistive at 28VDC or 115 VAC for life of 100,000 cycles. Case length approximately 1½", diameter ⅝". 3) Type B relay with crystal case meets all requirements of Military Standard drawing MS-24250. Available as type BR, with internally mounted silicon rectifiers for use at 400 cps AC or higher.

Contact rating is 2 amperes at 28 VDC or 115 VAC for a life of 100,000 cycles. Suitable for vibration of 30G to 2,000 cps minimum.

Hi-G uses a balanced rotary type armature which they have found to be the best design for resisting extremes of vibration and shock. In addition, they do not use springs to return the armature. Molybdenum contact leaves furnish the return force, allowing full use of magnetic force for contact pressure.

In relays rated for over 5g vibrations, Hi-G uses a permanent magnet to eliminate resonant vibrations that may occur in the armature under unenergized conditions. This Alnico V magnet doesn't fatigue as does a spring.

As the relay is energized effect of the permanent magnet is reduced! Using these techniques, Hi-G has produced relays for operation under 50g vibration to 1000 cps.

Circle No. 124 on Inquiry Card

WORTH FILING

### Magnetic Tape Instrumentation

Twenty-four page catalog describes and illustrates Honeywell multichannel magnetic tape system for laboratories, test cells, telemetering recording and other precision applications. Extensive performance specifications are given for transports, FM PDM, Direct and Digital tracks.

**Source: Minneapolis-Honeywell Regulator Co.**
**Beltsville, Md.**
**For your copy: Circle No. 109 on Inquiry Card**

WORTH FILING

### Ferrite Devices

New bulletin gives detailed specifications for over 35 devices which include circulators, high-power isolators, broadband test equipment isolators and complete ferrite duplexer packages. The ferrite isolators cover S-band through V-band; the circulators cover C-band through Ka-band; and the duplexers, X-band through Ka-band. The ferrite duplexers are custom matched, tube to circulator, to insure optimum performance.

**Source: Microwave Associates, Inc.**
**Burlington, Mass.**
**For your copy: Circle No. 107 on Inquiry Card**

# PRECISION GYROS

*A Proven Kearfott Capability.* The increasing use of Kearfott gyros and gyro platforms in today's missile programs, underscores the company's leadership in gyro design and production. Such missile projects as the Atlas, Bomarc, Polaris, Snark, Subroc and Talos rely on Kearfott gyros or gyro platforms, as do the majority of manned aircraft now in service.

***FLOATED RATE INTEGRATING GYROS.*** High accuracy miniature gyros specifically designed for missile use. The performance characteristics of these gyros are superior to any comparably-sized units available today. Hermetically sealed within a thermal jacket and ruggedly designed for adaptability to production methods. These gyros operate efficiently at unlimited altitudes. More precise performance characteristics can be provided in the same dimensions.

***TYPICAL CHARACTERISTICS***

Mass Unbalance:
Along Input Axis: 1.0°/hr maximum untrimmed
Standard Deviation (short term):
Azimuth Position: 0.05°/hr
Vertical Position: 0.03°/hr
Drift Rate Due to
Anisoelasticity: Steady
Acceleration: .015°/hr./g² maximum
Vibratory Acceleration: .008°/hr./g² maximum
Damping:
Ratio of input angle to output angle is 0.2
Characteristic Time:
.0035 seconds or less.
Weight: 0.7 lbs.
Warm-up Time:
10 minutes from −60°F
Life:
1000 hours minimum

***VERTICAL GYROS.*** Provide accurate vertical reference in the form of two 400 cps synchro signals proportional to the sine of gimbals' displacement about pitch and roll axes. Gravity-sensitive vertical reference device provides electrical signals directly to torque motors which maintain gyro spin axis perpendicular to earth's surface. Hermetically sealed, they are unaffected by sand, dust, sun, rain, salt spray, humidity or fungus conditions as specified in MIL-E-5272A.

***TYPICAL CHARACTERISTICS***

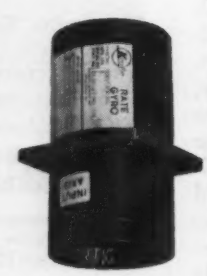
Repeatability to Established Vertical: To within a cone of half angle equal to 15 minutes of arc (± 8 minutes typical).
Free Drift Rate in 5 minutes Time: 2.5° maximum at room temperature. 3.75° at −54°C and + 71°C.
Erection Rate: 2.5°/Min.
Initial Erection: The gyro will erect to within ± 1° of established vertical in 60 seconds time after application of power at room temperature.
Vibration and Shock: The gyro will meet above characteristics after vibration of 0.060" total excursion cycling between 10 CPS and 55 CPS for 4.5 hours. Shock test in accordance with MIL-E-5272A Procedure 2.
Operating Life: 1000 hours minimum.

***FREE GYROS.*** Provide extremely accurate reference in the form of electrical output signals proportional to displacements about outer axes. With 360° of freedom about outer axes (inner axis freedom depends on the unit involved), these gyros may be mounted to give output signals of either pitch, roll or yaw. Shock and vibration resistant, they are equipped with quick-starting motors for applications in high performance missiles and aircraft.

***TYPICAL CHARACTERISTICS***

Free Drift Rate: Within 0.5° in one minute time.
Shock: The gyro operates satisfactorily without damage after 60g shock of .015 seconds duration.
Hermetically Sealed: These instruments are hermetically sealed and are not affected by sand, dust, sunshine, rain, humidity or fungus conditions.
Operating Temperature Range: Gyros operate in ambient temperatures below −20°C to + 100°C. A maximum of 3 minutes of operation at 400°F will not damage these gyros nor impair their accuracy.
Weight: 5.5 lbs. approximately.

***SPRING RESTRAINED RATE GYROS.*** Almost universally applicable in missile and aircraft designs demanding precise angular rate measurements in environments of extreme shock and vibration. Fluid filling provides added immunity to shock and vibration, reduces bearing friction in AC types and potentiometer wiper friction in DC types. Kearfott design advances permit 30 second warm-up, overcome fluid viscosity variations resulting from ambient temperature change. These gyros are single-degree-of-freedom, viscous damped, spring restrained, with gimbals supported by precision bearings. Compensatory damping mechanisms eliminate need for accessory heaters.



***TYPICAL CHARACTERISTICS***

Maximum Rate (°/sec.): 45-1000
Natural Undamped Frequency (cps) (± 10%): 16
Damping Ratio (of critical) over Temperature Range: .35 to .80
Operating Temperature Range (°F): −65 to +185
Vibration: 12 g's @ 20-2,000 cps
Shock (Motor Running): 60 g's for 6.5 milliseconds
Warmup Time (Sec.): 30
Weight (lbs.) (max): 1.5
Gyro Time Constant (Sec.): .012

***Engineers:*** Kearfott offers challenging opportunities in advanced component and system development

Roll Stabilized Directional Gyro

3 Gyro—4 Gimbal Gyro Reference

25 Pound Inertial Platform

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CIRCLE 24 ON INQUIRY CARD

## ELECTRICAL SHIELDING TAPE

### Quieting "Crosstalk"

Inter-communications wire "crosstalk" —a nuisance under any circumstances, and one that is particularly hazardous in aircraft—now can be virtually eliminated through use of a new electrical shielding tape called "Metalshield", introduced by the Dobeckmun Co., a division of the Dow Chemical Co.

"Crosstalk" results from inductance; i.e., the leakage of sound or conversation from one line to another. Its effect is a rise in static and background noise, which in some instances approaches jamming proportions. Naturally, when occupants of an aircraft moving at a speed faster than sound are unable to communicate properly either with one another, or with a ground station attempting to warn them of, say, a sudden weather change, the chances of an accident are significantly higher.

"Metalshield," according to James Flynn, Dobeckmun's electrical product manager, is not only far more effective in preventing inductance than other shielding materials, such as braided copper wire, but also over 50 percent smaller, roughly 34 percent lighter and substantially easier to apply.

All these factors, he points out, are of considerable importance to any industrial or commercial user of intercommunications equipment. A particularly pertinent example, he adds, is the fact that a jet aircraft requiring less space for communications equipment can hold more fuel per trip, with a consequent increase in flying range.

**"Metalshield" is produced first by laminating 0.00035" aluminum foil to 0.0005" Mylar, Dupont's polyester film, then by slitting to desired widths. The firm chose these thicknesses to fulfill strength needs and assure proper tensions in winding machines. Heavier gages of Mylar or foil can be used when deemed necessary.**

As to why "Metalshield" is more effective than other shielding applications in preventing "crosstalk," Mr. Flynn notes that braided copper wire, for example, when wrapped around a set of communications wire, does not provide a solid cover, thus permitting a certain amount of inductance, and, therefore, "crosstalk." "Metalshielding," on the other hand, can be applied in a solid wrap, directing all induced currents to a drain wire, which can be soldered or bolted to a ground.

Circle No. 81 on Inquiry Card

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### Zirconium-Copper Alloy

A new zirconium-copper alloy has been developed that possesses excellent conductivity and high-temperature strength properties. Applications include fine wire, resistance welding wheels and tips, rectifier bases, rotor wedges, studs for x-ray tubes, and electronic tube side rods. A typical bar of this alloy, cold-worked 60% and aged for one hour at 400 C, exhibits the following: tensile strength, 63,000 psi; yield strength, 59,000 psi; elongation, 12%; and electrical conductivity, 90-95%. At 400 C, the short time tensile strength is 46,500 psi. Additional cold-working will increase the strength of AMZIRC alloy without sacrificing ductility and electrical conductivity. Endurance tests show it to be far superior to unalloyed copper. The high softening temperature of AMZIRC alloy permits welding, brazing and silver-soldering. Silver plating is also practical with only minor modifications in procedures. Billets cast with the new alloy are free of inclusions and flaws — hence have better hot and cold workability. A new brochure describing properties and end uses of AMZIRC alloy has just been published. This eight-page booklet, illustrated throughout with charts and graphs, is available upon request to:

**Source: American Metal Climax, Inc.**
**New York, New York**

**For Your Copy: Circle No 246 on Inquiry Card**


COMPUTING COMPONENTS FROM Librascope

*Shaft-to-digital encoders meet rigid requirements*

Librascope shaft encoders meet and surpass rigid requirements of airborne analog-to-digital translation. Shock, vibration and temperature extremes do not affect their continuous, noise-free operation.

**THEY'RE DIRECT:** A simple one-step means of digitizing analog data.

**THEY'RE RELIABLE:** Multi-million turns at high speeds with constant contact resistance.

**THEY'RE VERSATILE:** 14 basic models in wide range of capacities; special function codes built-in to simplify computer requirements.

*For full details on Librascope encoders write for Catalog E11-1*

| OUTPUT CODE | MODEL NO. ◉ | TOTAL CAPACITY | RESOLUTION PER TURN |
|---|---|---|---|
| PARALLEL BINARY (LINEAR) | 740<br>743 | 10 bits (1024)<br>13 bits (8192) | 1024<br>128 |
| SERIAL BINARY (LINEAR) | 707<br>713<br>717<br>719 | 7 bits (128)<br>13 bits (8192)<br>17 bits (131,072)<br>19 bits (524,288) | 128<br>128<br>128<br>128 |
| SERIAL BINARY (SIN-COS) | 757†<br>758† | 7 bits per quadrant* (4 quadrants)<br>8 bits per quadrant* (4 quadrants) | 512<br>1024 |
| BINARY CODED DECIMAL (8-4-2-1) | 723<br>724<br>733<br>734<br>735 | 2,000<br>20,000<br>3,600<br>36,000<br>360,000 | 200<br>200<br>200<br>200<br>200 |
| GRAY | 708 | 8 bits (256) | 256 |

◉ All models available with internally mounted isolation diodes for sequential multiplexing applications.
†Available in hermetically sealed servo-driven package as Models 757-S and 758-S.
*Including limit 1 and polarity information. Sine and cosine functions generated simultaneously and independently. One turn of shaft generates 4 quadrants of information.

LI 9-17

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LIBRASCOPE, INC. Commercial Division
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CIRCLE 25 ON INQUIRY CARD

# New center screwlock connectors for heavy duty applications

## from Continental Connectors

Continental's new center screwlock connectors are designed with high dielectric and mechanical strength for heavy duty applications in aircraft and electronic equipment. Features include a double lead thread screwlock, stainless steel reinforcing channels riveted to plug and receptacle, closed entry contacts and positive polarization through guide pins and sockets. At present the body is molded from glass filled Diallyl Phthalate, but other compounds as well as hoods and protective shells will be available soon.

*Closed Entry Socket Contacts* are spring temper Beryllium copper, gold plate over silver plate. They provide increased reliability and maintain a low millivolt drop under constant and uniform insertion pressure. Pin contacts are brass with gold plate over silver plate.

For full details on Continental's new Series 1900 center screwlock connectors, write DeJUR-Amsco Corporation, 45-01 Northern Boulevard, Long Island City 1, N. Y. (Exclusive Sales Agents)

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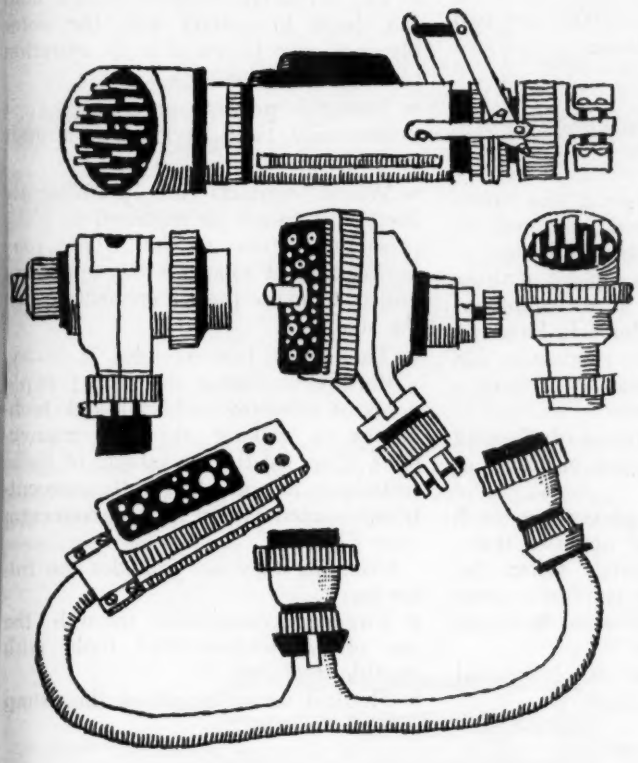
*You're always sure with* **DeJUR** electronic components

MANUFACTURED BY CONTINENTAL CONNECTOR CORPORATION, AMERICA'S FASTEST GROWING LINE OF PRECISION CONNECTORS

CIRCLE 26 ON INQUIRY CARD



COMPONENTS 6 DIGEST

# CONNECTORS PART II

## RF Connectors

Cable for RF transmission is generally coaxial, comprising a central conductor surrounded by a concentric braided shield. A suitable dielectric, frequently air, separates the two. RF connectors terminate coaxial cable, to interconnect RF circuits. Connections are required between the braided shield and central conductor, and the corresponding portions of the connector. In most popular connectors the cable braid retention device constitutes the main mechanical anchorage between cable and connector. Pull strength as well as most of the selection factors applied to MS connectors as described previously, are applicable to RF connectors and must be so considered.

Figure 1 shows an Amphenol connector and illustrates some of the design features required to maintain good electrical contact, high holding force, and a minimum interference with the flow of RF power. In this type connector it is necessary not only to achieve a satisfactory electrical connection at high frequency, but at the same time to preserve the cable impedance characteristics. Electrostatic and electromagnetic shielding as well as a uniform distribution of parameters are important. Any discontinuity in coupling sets up reflections which introduce distortion and power losses and interfere with the flow of RF power. Portions of the *output* energy are reflected back to the transmitter. The voltage standing wave ratio (VSWR) is a measure of reflections introduced by the connector. A value of unity indicates the absence of such reflections. A figure greater than unity indicates their presence. The VSWR must be as close to unity as possible, and is a measure of quality, particularly above about 100 Mc.

**TABLE I**
**Military Specifications for RF Connectors**

| | |
|---|---|
| MIL-C-71A | Series N RF connectors |
| MIL-C-3989 | Series C RF connectors |
| MIL-C-3608 | Series BNC RF connectors |
| MIL-C-3643 | Series HN RF connectors |
| MIL-C-3655 | Series UHF RF connectors |
| MIL-C-3650 | Series LC RF connectors |

For circuits requiring matched impedance, it is necessary to continue the cable geometry directly into the connector. Provision is made for continuation of the cable shield as well as the contact pin through the connector with minimum change in diameter. In application the cable dielectric must be in firm contact with the dielectric of the connector insert, since an air gap here introduces an impedance discontinuity.

RF connectors are available in an assortment of configurations to match standard RF cable. Military specifications which cover most RF connectors are listed in Table I.

Design requirements on RF connect-

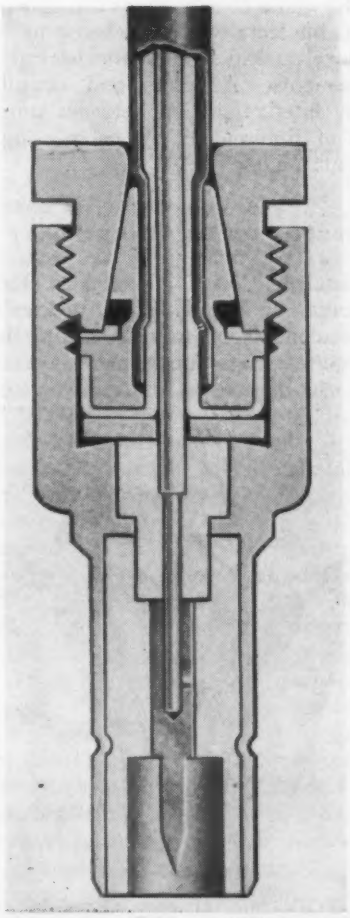


**Fig 1 Subminiature RF jack by Amphenol illustrating important design features.**

COMPONENTS DIGEST 6

ors emphasize miniaturization and reliability. The behavior of solderless connections is still a matter of controversy at the high end of the RF spectrum (thousands of megacycles). Connectors have been designed using crimping techniques to both the center conductor and its concentric shield. It has been argued that strains imposed during crimping may introduce localized discontinuities in the cable dielectric. Soldering on the other hand calls for considerable skill to avoid damaging the cable dielectric by overheating. Figure 2 shows several cable fastening methods employed by manufacturers.

The selection of RF connectors is based to a large extent upon circuit requirements, power handling capacity, upper frequency limit, matching impedance and voltage rating. Additional selection factors include miniaturization and environmental requirements. An assortment of suitable connector cable combinations are generally available from which to choose to meet both electrical and non-electrical requirements. Adapters and couplings allow interconnection between connectors of different types, or meeting at various angles.

### PROBLEMS ON RF CONNECTORS

Michael D. Lazar, Connector Design Manager of Burndy Corp. divides coaxial connector problems into three categories: those problems inherent in the use of solder; those involved in connecting the shield; and high assembly cost.

Mr. Lazar elaborates on the first two of these factors as follows:

*Solder*

- A "cold solder joint" is indistinguishable from a good one, and it is unreliable.
- The heat of soldering the inner conductor or the shield may melt or burn the inner conductor insulation.
- A solder joint leaves a point of stress concentration on the inner conductor, which can lead to failures in handling and service in the fine conductors (28 to 30 ga) used so widely in today's miniature coaxial cables.
- Fluxes and the problems of cleaning may precipitate corrosion of the connection.
- The conductors and parts are so small that a high degree of operator training and skill is required. Often the soldering of the inner conductor must be done under magnification to insure a good rate of success.
- Quality varies with the individual operator.

*Shield Connections*

- The screw-type devices which hold the shield in contact with the outer element may loosen due to vibration causing RF noise in a circuit.
- Excessive pressure on a screw-type device may twist and break strands from the shield.
- Where contacts are permanently fixed into panels or mounted in close proximity to one another, there may be insufficient room for the operator's fingers to make proper connections on the shield.
- The screw type coupler is bulky.

Burndy is among the strong exponents of crimping and snap-lock techniques in making electrical connections. They list the advantages of these techniques as embodied in their recently introduced Hyfen coaxial connector (see Fig 3).

Crimping they say provides the following:

- Uniform connections through the use of ratchet-controlled tools with durable steel dies.
- Physical measurement of the crimp

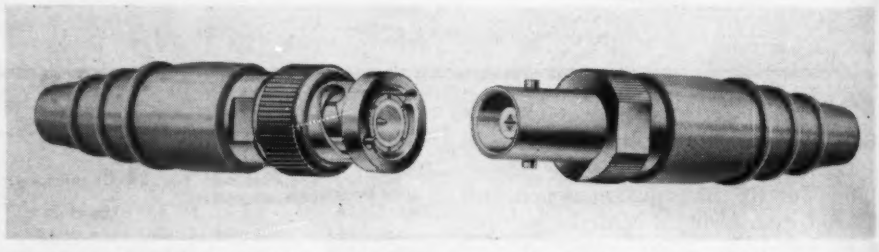


**Fig 2(c) Quick-Crimp BNC's. A complete new series of crimp-type BNC connectors featuring simplicity of assembly and improved electrical and mechanical characteristics. Courtesy of Amphenol.**

**Fig 2(b) Special coaxial cable connector by Barker and Williamson provides water-tight coaxial connections for antennae.**

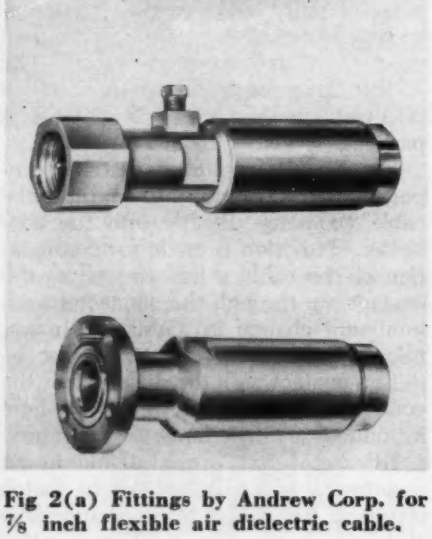


**Fig 2(a) Fittings by Andrew Corp. for ⅞ inch flexible air dielectric cable.**

**Fig 2(d) Polarized twin contact BNC type bulkhead mounting receptacle and plug designed for use with RG-108A/U twin conductor cable. Courtesy of Amphenol.**

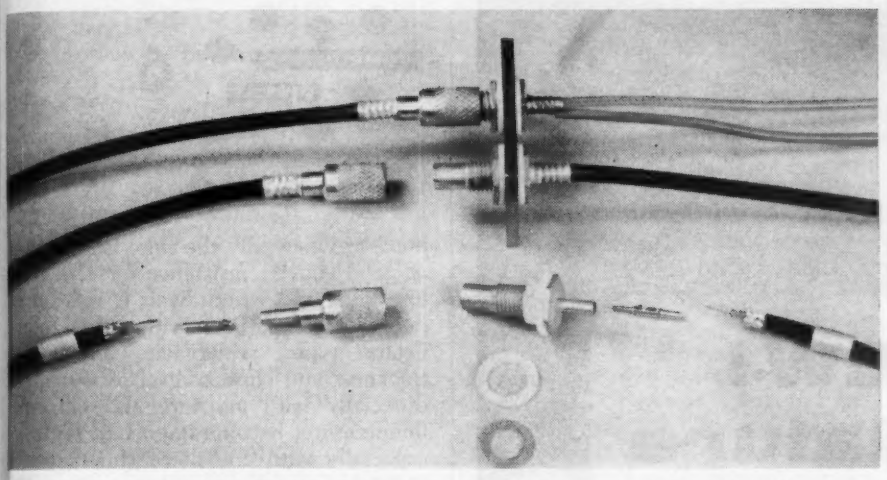


**Fig 3(a) Flange mounted coaxial cable connector. Burndy coaxial Hyfen connector used in individual flange mounted applications, provides for crimp connections with snap-lock assembly. Figure shows (top) coaxial cable to twisted pair connection, (center) coax cable splice, and (bottom) exploded view of connector components.**

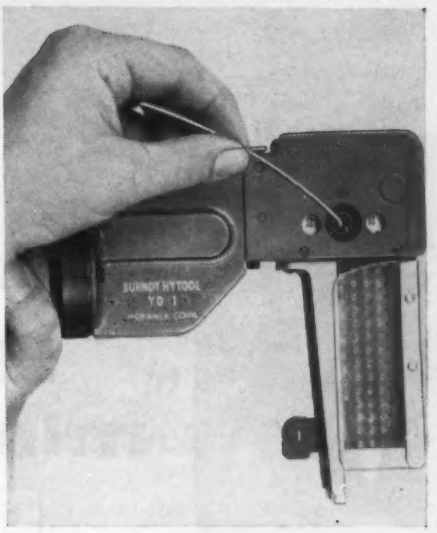


**Fig. 3(b) Burndy semi-automatic high speed crimping tool installs magazine fed contacts for Hyfen applications.**

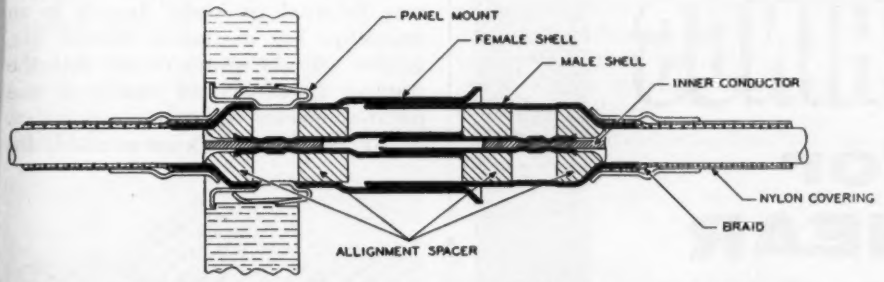



**Fig 4(a) Coaxicon for quick operate splice for coaxial cable.**

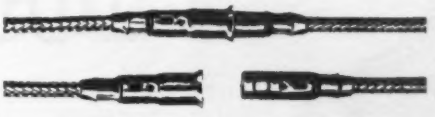


**Fig 4(b) Details of simple splice by AMP for coaxial cable.**

provides an easy and accurate micrometer check of each connection.

- No heat is used.
- Noise-free performance tested up to 150 Mc frequency after severe environmental conditions.
- Low resistance plating maintained unbroken, providing high corrosion resistance.
- Depth of indent control eliminates possibility of damage to conductor strands.
- Relatively unskilled operators make quality connections after a minimum of training. This contributes to low installed cost.
- Diameter of assembled connector is maintained close to the cable diameter due to elimination of screw-types couplers.

Snap-locked contacts, Burndy engineers say, provide these advantages:

- Contacts may be installed to cables wherever convenient prior to final assembly of harnesses to connectors. Connectors may be pre-mounted to equipment prior to assembly with harness.
- Ability to make changes conveniently provides for greater flexibility in wiring.
- Low installation cost due to snap-in simplicity.
- Damaged contacts may be snapped out and replaced without replacing the complete connector.
- Inspection of connection is simplified by easy inspection of sub-assemblies prior to final mounting.

Also employing crimping techniques AMP, Inc. has developed their Coaxicon splices to provide a quick connect/disconnect splice for coaxial cable. Figure 4(a) shows how the splice is simply effected, while Fig 4(b) illustrates the details of internal construction. A precision tool crimps both center conductor to contact and outer braid to splice shell in one stroke. The special construction prevents variations in crimps to assure uniform attachment.

The debate on solder vs. solderless connections is still going on. It is claimed that

- Solderless or crimped connections may cause noise after wide temperature cycling due to non-uniform coefficients of expansion. A corrosive atmosphere may oxidize metal surfaces during the cyling process where the connection may shift somewhat. This is impossible with solder.
- Crimping on an RF shield may deform the cable dielectric introducing reflections.
- Many soldering problems are overcome by resistance soldering similar to resistance welding, but with the introduction of solder. Heat is applied only at the contact point, avoiding burning of insulation. This is a good production process.
- Solder joints generally provide less reflection to microwave frequencies.

### Printed Circuit Connectors

The increasing importance of printed circuits and modular packaging in the fabrication of electronic equipment has led to the development of an assortment of printed circuit connectors. Due to newness of this type connector as well as the large quantities used, much attention is being paid to proper application to secure necessary reliability. Some printed circuit connectors are shown in Figs 5 through 7. The initial selection factor is based upon the board thickness which the connector is required to match.

The factors involved in selecting printed circuit connectors are much the same as for conventional connectors although the nature of the structure limits certain performance features. Particularly compact is the one piece connector where plug contacts are printed directly on the circuit board. The simple arrangement of contacts, one alongside the other lacks the versatility of the two dimensional array in MS connectors. However, heavy power terminals are rarely required. Higher contact resistances, many mil-

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lions, are generally the rule. Endurance of good contact resistance for repeated insertions and withdrawals is relatively poor in comparison with other connector types. Tolerances on board thickness and close control of warping, especially with moisture and extreme temperature, become important factors, especially with one piece connectors.

Printed circuit connectors are usually suitable for dip soldering on printed circuit boards, or for conventional wiring techniques. Polarity is maintained by polarizing pins or slots in the connector. More than one polarizing pin may be used to "code" boards in an assembly. For maximum contact life, guides may be provided so that the printed circuit board enters a one piece connector squarely.

RF coaxial sockets are available for

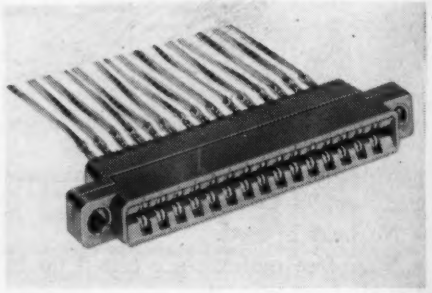

**Fig 5(a) A protective taper tab enclosure has been designed into this 15-contact Continental printed circuit connector to prevent the possibility of bending, twisting or shorting the contacts during assembly. The special molded body is an integral part of the connector and assures uniform spacing of contacts. Contact terminations accomodate "AMP 78" taper tab receptacles for solderless wiring.**

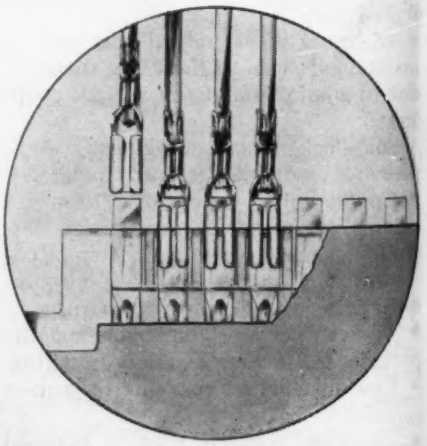

**Fig 5(b) Enlarged view of solderless terminals to show detail.**



CIRCLE 27 ON INQUIRY CARD

attachment to printed circuit boards. These may be suitable for dip-soldering but, in view of the force exerted when a plug is removed, additional supports to the board are provided.

A special variety of printed circuit connector has been designed to provide test points for checking out an electronic test subassembly. These are assembled to the printed circuit board and provide "read out" points for making test point connections with an appropriate mating plug, Fig 8.

Figure 9 illustrates an application factor peculiar to the printed circuit, namely the matter of orientation. The connector may be located at a variety of angles with respect to the circuit board as determined by the requirements of the application. The variety of connector terminations depending on the type of connection and whether both sides of the connector plug contain separate circuits is illustrated.

### RECENT SURVEY

A recent survey sponsored by Wright Air Development Center and conducted by Stanford Research Institute constitutes an important basic reference on this subject. This report entitled "Preparation of Standards and Test Procedures for Printed Circuits" contains, in addition to a laboratory evaluation of many types of printed circuit connectors, a summary of a questionnaire sent to both manufacturers and users of printed circuits. The object of this questionnaire was to determine the reliability of printed circuit connectors in field equipment and the nature of the failures which were occurring. The questionnaire answers indicated that failure rates for printed circuit connectors are as nearly as could be determined, below 1 percent. Connector manufacturers felt that their products are frequently misused by producers of electronic equipment, thereby generating an undeservedly poor reputation for the connectors. Furthermore, connector manufacturers claimed that the lack of information from connector users on the causes of connector failures, makes it difficult to improve their products. Connector users state that usually they themselves cannot determine the causes of connector failures.

The report continues that manufac-

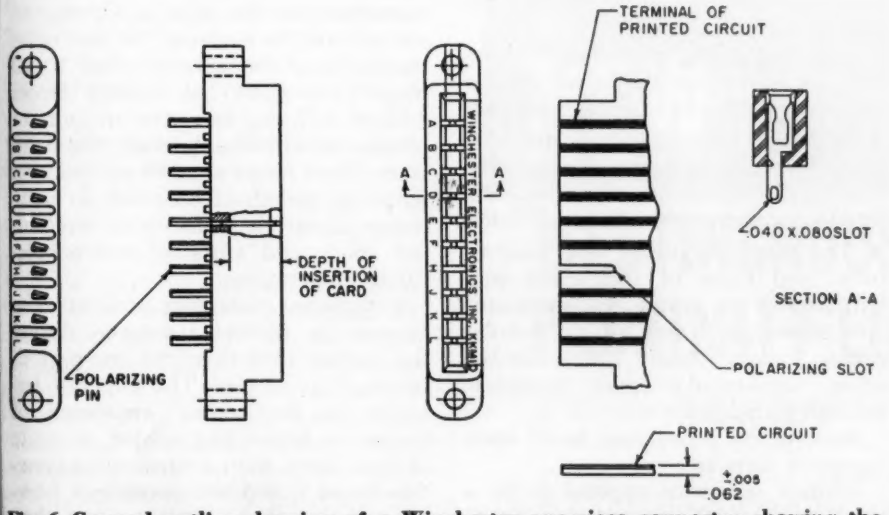


**Fig 6 General outline drawing of a Winchester one-piece connector showing the polarizing pin and mating slot.**

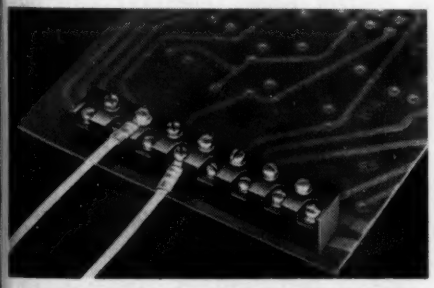

**Fig. 7 Miniature terminal block by Kulka for making connections between external wiring and printed circuit boards. Recessing alternate screws as shown permits extremely compact spacing. The entire connector unit is mounted on the board by dip-soldering the pins (not shown) within the connector mounting holes.**

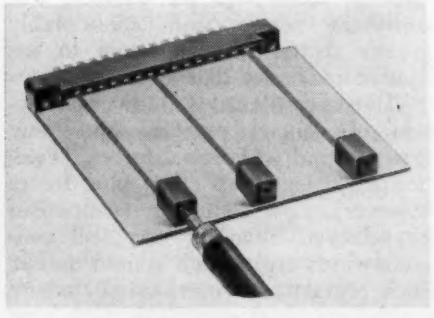

**Fig 8 Continental Test Point Connector. Test points can be conveniently located at any position on the printed circuit board for easy test take off points. Socket contacts are spring temper phosphor bronze, gold plate over silver plate.**

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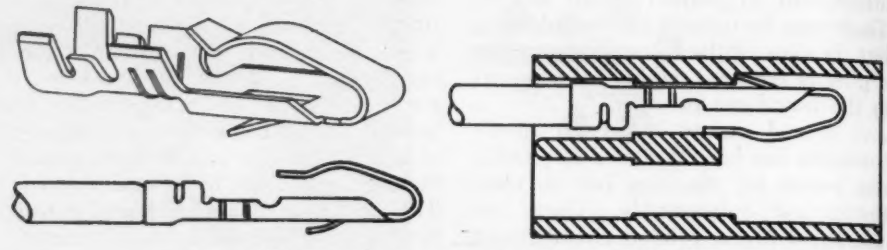

Fig 9(b) Detail of connector contact by AMP.

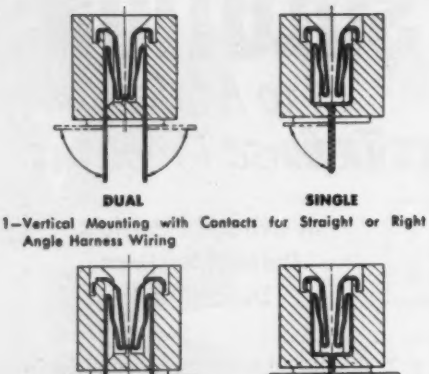
DUAL
SINGLE
1—Vertical Mounting with Contacts for Straight or Right Angle Harness Wiring
DUAL
SINGLE
2—Vertical Mounting with Contacts for Dip Soldering to Underside of Printed Circuit Board
DUAL
SINGLE
3—Vertical Mounting with Contacts Soldered to Top Side of Printed Circuit Board
DUAL
SINGLE
4—Right Angle Mounting with Contacts for Dip Soldering to Underside of Printed Circuit Board

**Fig 9(a) Continental "Bellows" contacts showing the variety available to suit required orientation as well as manufacturing techniques.**

turers of connectors felt that one-part printed circuit connectors are not inherently less reliable than any other types of connectors, and that any difficulties experienced in their use could probably be rectified by improved connector design and, particularly, proper connector use. Connector users are not predominantly in favor of any particular type of connector. No trend away from use of one-part connectors is evident. The two most popular types of contacts used in one-part connectors are those stamped from sheet stock and those made from convoluted metal ribbon. A trend away from stamped contacts was indicated, however, because of damage to the inserted foil contacts by sharp edges, and relaxation of contact pressure due to stressing of the contacts above their elastic limit.

As a result of a survey of printed circuit manufacturers, a number of conclusions were reached.

- The most used printed circuit base materials are paper, phenolic laminates, and glass-epoxy laminates, copper-clad on two sides. The most used based material thickness is 1/16 inch.
- Gold-plating is the most frequently used plating over printed circuit conductor patterns; plated solder is a close second. These platings are used primarily to reduce oxidation during storage and to enhance solderability.
- Dipped-tin component leads and gold-plated terminals are preferred because of enhanced shelf-life and solderability.
- Lead-tin solder containing 60 percent tin is by far the most popular for both hand and dipped soldering.
- Although no single factor tends to completely control solder joint quality, soldering temperature was frequently listed as an extremely influential factor.
- The most frequently and successfully used types of component lead terminations on printed circuit boards are: shoe-type eyelets, flared tubular eyelets, plain holes with clinched wires, semi-tubular rivet terminals, through-plated holes.

Some of the conclusions based upon connector tests are:

Contact resistance appears to be a good measure of connector performance—plug insertion and withdrawal force is much less so, showing less consistent results and considerably greater scatter in comparison to the contact resistance data obtained.

Contact resistance is an inverse function of contact pressure and plug insertion and withdrawal forces. (Friction coefficients also effect plug forces however). Low contact resistance can be achieved by using very stiff contacts which create high contact forces. Such contacts, however, usually create problems such as excessively high plug insertion force (particularly in connectors which contain many contacts) and torn foil contacts on one-part connector plugs.

Generally speaking, one-part connectors displayed higher and more scattered values of contact resistance than either two-part or composite connectors. This is probably attributable in part to the following factors:

- Both of the mating contacts in two-part and composite connectors are normally plated with gold or gold alloy. One-part connector receptacle contacts are usually similarly plated; however, the contacts on one-part connector plugs are normally plated with a relatively hard metal, which has a much higher electrical resistivity than gold.
- Contact pressures (and, consequently, contact resistance) in two-part and composite connectors are primarily dependent upon the mechanical and physical properties of the contacts. Contact pressures in one-part connectors, on the other hand, depend not only on the contacts, but also upon the ability of the printed circuit board plugs to support the contact forces without suffering excessive amounts of plastic deformation beneath the contacts. These forces must be carried over indefinite periods of time and, in some instances, in environments of mechanical shock and vibration and/or elevated temperatures.

Composite connectors suffered less increase in contact resistance during the various tests than did one-part or two-part connectors. This superior behavior in the contact resistance of composite connectors existed in spite of their lower than average plug-insertion forces. Composite connectors, however appear to be more subject than the other types of connectors tested to contact noise (electrical interruptions) during environments of mechanical shock and vibration.

Contact plating is normally worn from contact surfaces within 100 cycles of plug insertion and withdrawal. Although some wear tests now involve thousands of such cycles, it was concluded that a test incorporating more than 100 cycles would be unrealistically severe.

Salt-spray conditioning is valuable in printed circuit connector testing only when used as an accelerated corrosion test. This conditioning was originally developed to evaluate the relative corrosion resistance of various coatings in sea-coast environments. Since its origin, the salt-spray test has been indiscriminately and too often

unrealistically adapted to other purposes. The laboratory work performed indicated that salt-spray conditioning was most valuable and sensible (as far as printed circuit testing is concerned) when used in conjunction with a contact continuity test. This procedure evaluates the ability of mating contacts to maintain electrical continuity in highly corrosive environments. It is unrealistic to expect unprotected printed circuit boards to operate satisfactorily following a 48-hour exposure to sea water. It is, similarly, pointless to expect similar performance from printed circuit connectors. The salt-spray test may be found useful in detecting leakage of hermetic seals, gaskets, or protective shells, but once the salt solution contacts an unprotected surface within a piece of electronic equipment, the equipment is rendered useless for future service.

As a result of the research on printed circuit connectors, certain recommendations have been formulated. These recommendations, listed below, are included in the interest of improving connector designs and of improving liaison between the manufacturers and users of printed circuit connectors. Factors affecting quality are summarized in Table II. Significant properties of one-part and two-part connectors are described in Tables III and IV.

- Contact spacing should be standardized to conform with recently-proposed 0.100-0.050, and 0.025 inch grid systems for automatically produced circuit boards.
- More thorough analyses of connector failures should be performed by connector users, and all significant findings relayed back to the connector manufacturers. In this way alone will the manufacturers be able to determine and correct weaknesses in their products which become apparent only under service conditions.
- Material requirements and certain design features of printed circuit board plugs used in one-part connectors should be standardized. For example, foil contact width and cure temperatures or creep limits for plastic laminates.
- Additional development work should be performed on one-part connector contacts to yield improved (lower and more constant) contact resistance characteristics with decreased (or at least not increased) plug-insertion forces—along with greater tolerances of thickness variations in the printed circuit board plugs.
- Improved methods should be developed for retaining the polarizing key in one-part connectors. Keys in several of the one-part connectors tested pulled out with the plugs.

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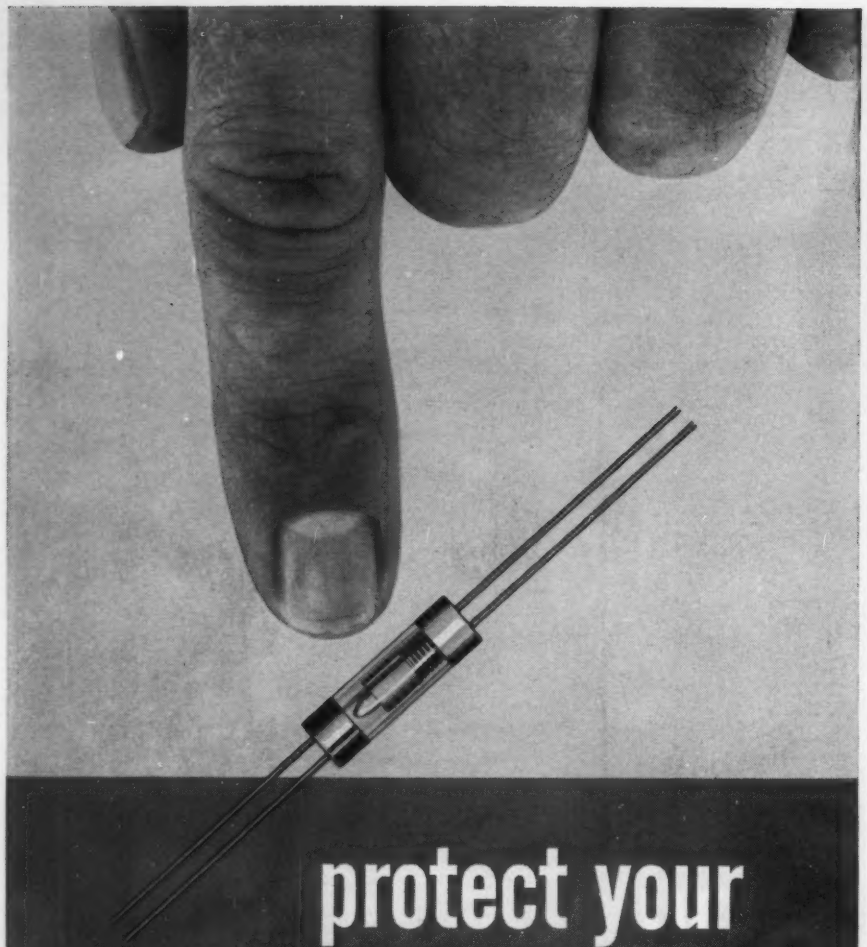

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**TABLE II**

**Factors Affecting Quality of Etched Printed Circuit Connectors**

Contact plating and its various effects.
Creep characteristics of plug base materials.
Design of the receptacle contacts and frame.
Chamfering of the inserted plug edge.
Surface contamination of the plug.
Warp or twist of the plug.
Thickness of the plug base material.
Type of plug base material.

**TABLE III**

**List of Properties Most Significant for One-Part Printed Circuit Connectors**

Uninterrupted electrical contact continuity during vibration.
Resistance to mechanical shock.
Unimpaired performance* under conditions of temperature cycling.
Minimization of moisture and dirt traps. Maximum wear-life of contacts. (Optimized contact platings.)
Acceptable performance at sea level as well as rarefied air.
High arc-resistance of dielectric material.
Connector frame and contact design which eliminates contact damage due to the insertion of overly thick or warped plugs.
Acceptable contact resistance at minimized insertion forces.
Maximum durability of foil tabs and tab bonding on plug to minimize the tearing of tabs.

*Connector performance includes such factors as consistently low contact resistance, resistance to arc-over, and chemical and mechanical stability and durability of dielectric and contact materials.

• An investigation should be conducted to determine the feasibility of and evaluate the advantages of producing connectors in which contact forces can be applied after plug insertion and released prior to plug withdrawal.

## Umbilical Connectors

Umbilical connectors derive their name from the fact that they join two electronic or electromechanical complexes: one within a missile or aircraft about to be launched and the other at some master control point on the ground. At launching (or birth) these connectors sever the circuits and the missile or aircraft is airborne. In

**TABLE IV**

**List of Properties Most Significant for Two-Part and Composite Printed Circuit Connectors**

Uninterrupted electrical contact continuity during vibration.

Resistance to mechanical shock.

Unimpaired performance* under conditions of temperature cycling.

Maximum wear life of contacts (Optimized contact platings.)

Acceptable performance at sea level as well as in rarefied air.

High arc-resistance of dielectric material.

Acceptable contact resistance at minimized insertion forces.

Proper installation and alignment of contacts on printed circuit board (composite-type connectors.)

*Connector performance includes such factors as consistently low contact resistance, resistance to arc-over, and chemical and mechanical stability and durability of dielectric and contact materials.

most cases umbilical connections are maintained right up to the moment of launching since the setup and checkout of missile systems are performed by electrical impulses passing through the umbilical connectors from instruments and control sources at the master control point. Disconnection of these communication and control lines is usually activated remotely either by action of the missile or aircraft itself or from a a master control point.

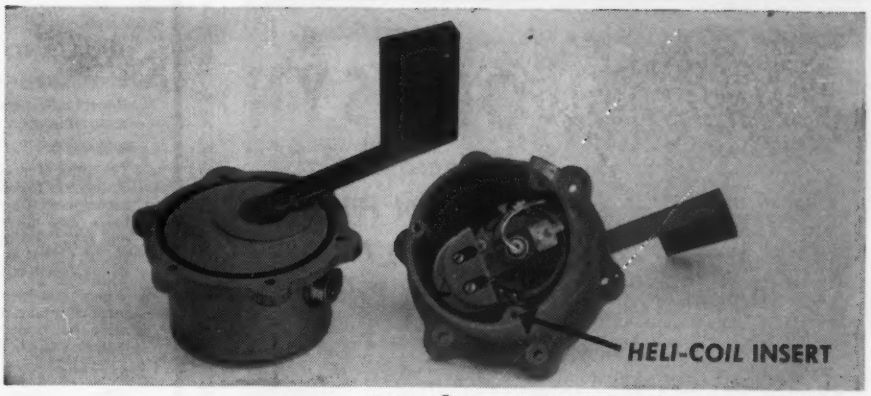
Umbilical connectors usually fall into three types based upon the launching method employed: vertical, rail and stage separation.

*Vertical Launching* Large IRBM and ICBM missiles are usually launched vertically. At a specific moment in relation to the firing or launch, the connector is disengaged or ejected by solenoid action, manual lanyard action or shear.

*Rail Launching* Rail launching is used in ground to air, air to air, or air to ground missiles. Air launched missiles are released from a rail hung under the wing or fuselage of the aircraft. Connector release in this case is usually of the shear type.

*Stage Separation* Multiple stage missiles employ umbilical connectors between stages. As one stage burns out, the next stage must be activated and separated from the spent stage. Explosive

*Continued on page 46*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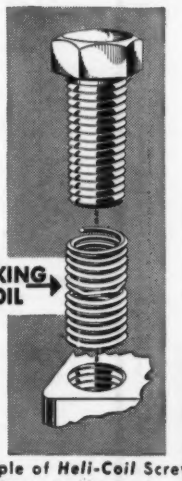


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**Small Size—2.3 dia x 15/16 length**
**Inertia—52 gm-cm² • Weight—7 oz**
**High Reliability — no brushes**

| MODEL | RESOLUTION |
|---|---|
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### BALL AND DETENT RELEASE

**DISENGAGED**

Receptacle is mounted on missile, the plug assembly is attached and secured in such a way to provide for its retrieve when released.

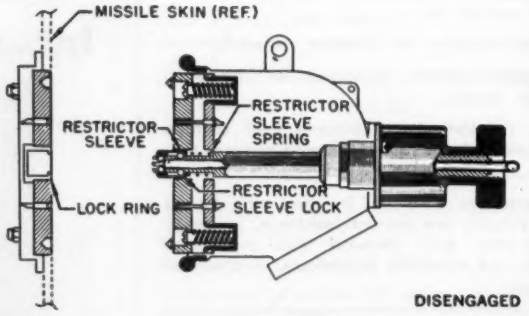
**ENGAGED**

The plug is pressed against the receptacle face to initially lock the connector together. This locking occurs as follows: the receptacle face forces the restrictor sleeve back to relieve the restriction on the balls. This allows the spring loaded detent shaft to release forward and force the balls outward. The balls then act as a lock by action of the detent shaft against the balls, and the balls against the neck of the receptacle lock ring.

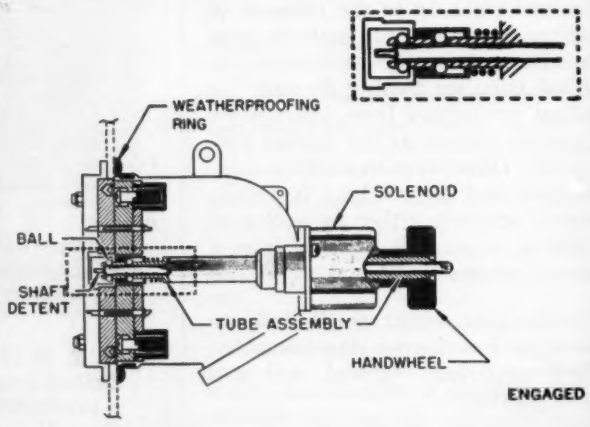
When thus locked, the handwheel is turned which compresses the receptacle and the spring loaded plug inserts together to completely mate the connector. This action also compresses the weatherproofing ring to seal off the connector.

**RELEASE**

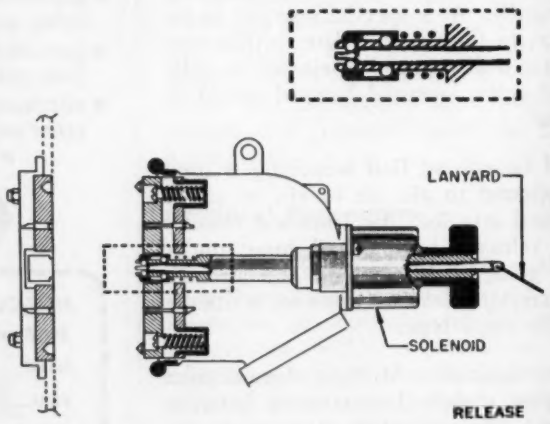
When a lanyard is pulled or the solenoid is actuated, the following occurs: the detent shaft is pulled back. This allows the spring load to force the now unrestricted outward balls down into the detent of the shaft. The lock mechanism is thus unlocked which permits the force of the spring loaded insert faces to separate the connector.




DISENGAGED




ENGAGED




RELEASE

Fig. 10(a)

## ALL PURPOSE RELEASE

**DISENGAGED**

This new all purpose release is designed to use interchangeably with connectors which otherwise use a ball and detent release.

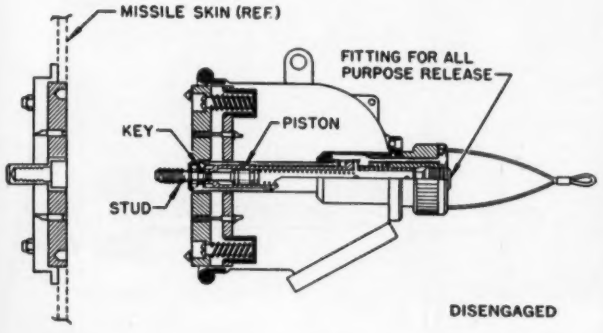
**ENGAGED**

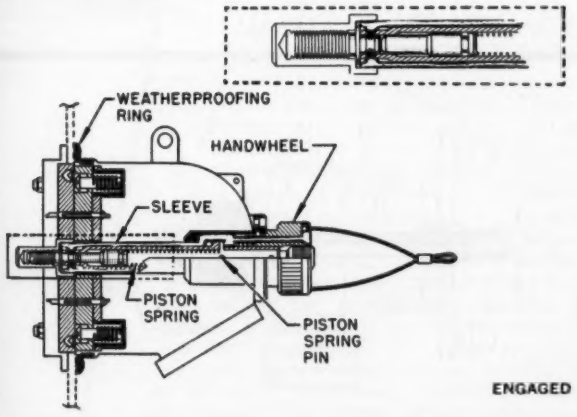
The plug is engaged by simply turning the handwheel which screws the stud into the receptacle. This action compresses the spring loaded plug inserts, and the weatherproofing ring against the missile skin.

**RELEASE**

When the lanyard is pulled, the sleeve assembly is also pulled back. This allows combined spring forces to snap the keys out into the now open cavity at the end of the sleeve. This action frees the stud, which allows the insert spring tension to release, thereby ejecting the plug from receptacle. An explosive squib, hydraulic fitting, or a pneumatic fitting can also be attached to the back of the release assembly. The release by these means is accomplished as follows: the pressure accumulation by either an explosion, fluid, or air, fills the tube. The pressure then expands through the vent and drives the sleeve back, effecting the same release as a lanyard pull.

When the connector is released, the stud travels with the receptacle. The plug may be re-used again by simply inserting a new stud.



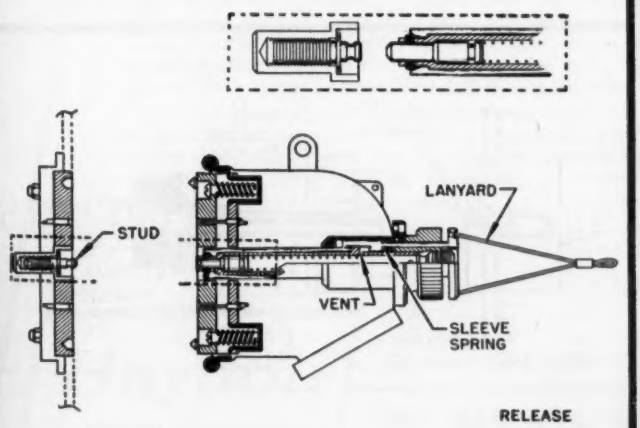




**Fig. 10(b)**


push-pull CONTROLS

**Compression & Tension Type**

Aircraft cable is strung with spherical steel shells in a rigid or flexible housing sealed with "O" rings. 3" standard bend radius. ¼" minimum bend radius.

**Three Types:**

1. *Light Duty*—Compression Ult. Load 1250 lbs.; Ult. tension 960 lbs.
2. *Heavy Duty*—Compression Ult. Load 1650 lbs.; Ult. tension 960 lbs.
3. *Extra Heavy Duty*—Compression Ult. Load 3050 lbs.; Ult. tension 3900 lbs.

Positive remote controls for actuating mechanical, hydraulic or other devices. Eliminate bell cranks, pulleys, and dua cables. U.S. Patent No. 2441719. All world rights reserved. Send for ENGINEERING MANUAL giving complete specifications covering materials, finishes, capacities. Please address Dept. EMD-PP-59.

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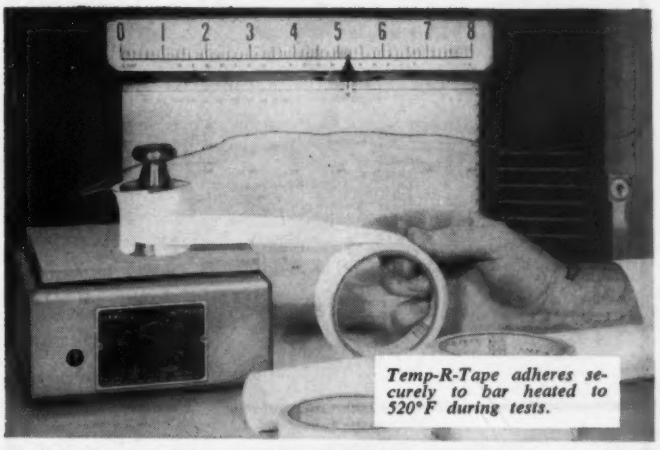

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Temp-R-Tape is available from stock in rolls and sheets. All four types — Temp-R-Tape T; TH; C and TGV — combine some form of Teflon backing with silicone polymer adhesive to provide easy-to-apply pressure-sensitive and thermal curing pressure-sensitive tapes for electrical and mechanical applications. Designed for extreme temperatures, Temp-R-Tapes possess high dielectric strength, low power factor, high elongation, negligible moisture absorption, are non-corrosive and non-contaminating.

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CIRCLE 35 ON INQUIRY CARD

## SHEAR TYPE RELEASE

**DISENGAGED**

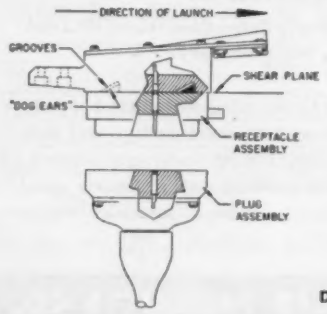
Receptacle is mounted to missile which is launched from a platform or rail.

**ENGAGED**

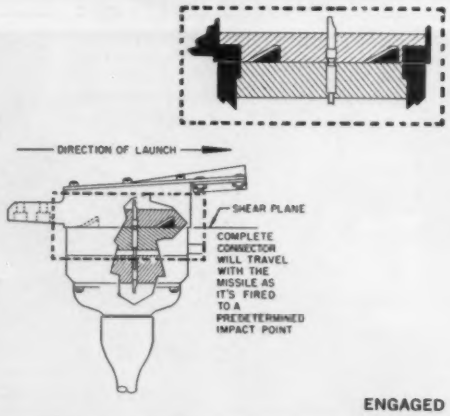
The plug is engaged and held to the receptacle by the design of the launching platform.

**RELEASE**

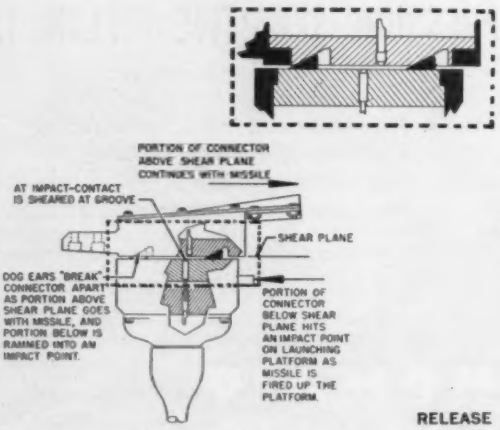
As the missile is fired from the launching platform, the exposed portion of the receptacle and plug are carried along to a predetermined point of impact. On impact, the receptacle portion above the shear plane goes with the missile. The portions below shear plane—stopped by impact—separate immediately. As the missile continues, the action of the grooves riding up and away from the dog ears, separate the connector to prevent any possibility of cross circuiting.




DISENGAGED


DIRECTION OF LAUNCH
SHEAR PLANE
COMPLETE CONNECTOR WILL TRAVEL WITH THE MISSILE AS IT'S FIRED TO A PREDETERMINED IMPACT POINT

ENGAGED


PORTION OF CONNECTOR ABOVE SHEAR PLANE CONTINUES WITH MISSILE
AT IMPACT-CONTACT IS SHEARED AT GROOVE
SHEAR PLANE
DOG EARS "BREAK" CONNECTOR APART AS PORTION ABOVE SHEAR PLANE GOES WITH MISSILE, AND PORTION BELOW IS RAMMED INTO AN IMPACT POINT.
PORTION OF CONNECTOR BELOW SHEAR PLANE HITS AN IMPACT POINT ON LAUNCHING PLATFORM AS MISSILE IS FIRED UP THE PLATFORM.

RELEASE

## EXPLOSIVE SHEAR RELEASE

**DISENGAGED**

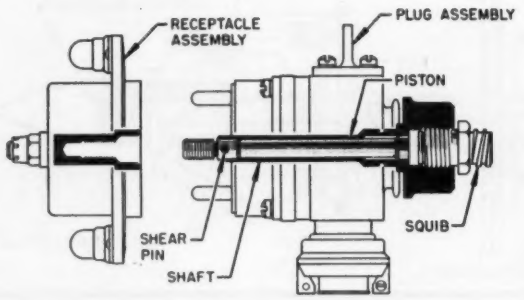
Receptacle is rigidly mounted... plug is cord mounted. The engaging stud is attached to the shaft by a shear pin.

**ENGAGED**

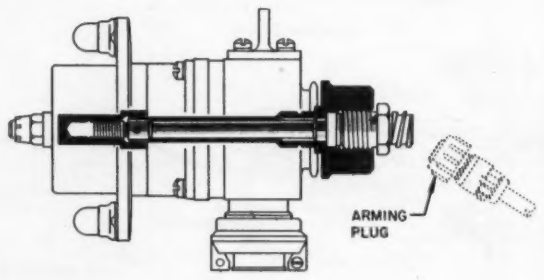
Connector is mated by turning handwheel at rear of plug assembly. An arming plug is then connected to the explosive squib assembly. Receptacle is mounted to missile which is launched from a platform or rail.

**RELEASE**

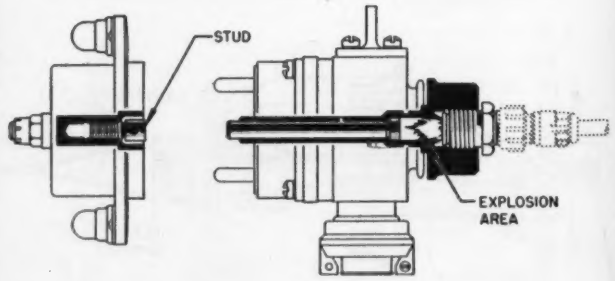
Current through the arming connector detonates the squib. The explosive force drives the piston to shear the pin and separate the plug and receptacle.




DISENGAGED

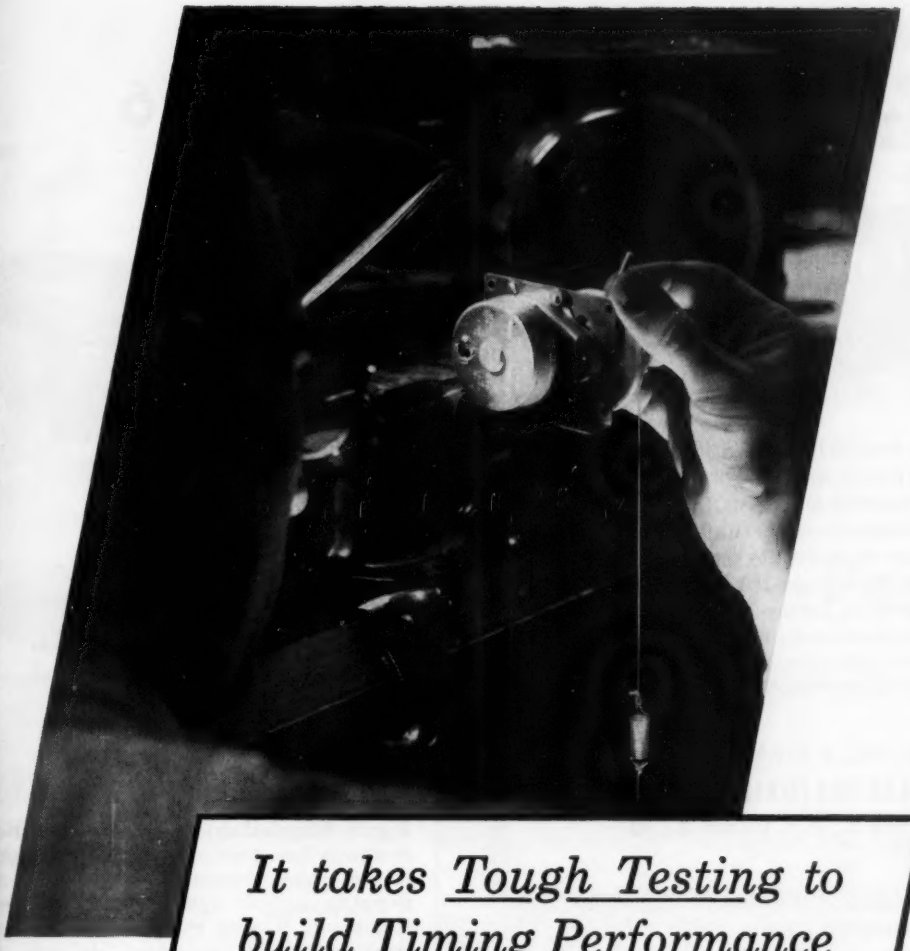



ENGAGED




RELEASE

Fig. 10(c)



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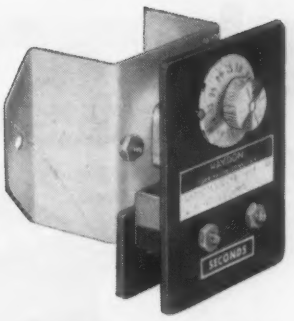
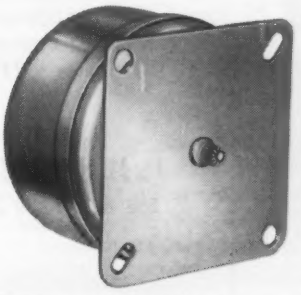


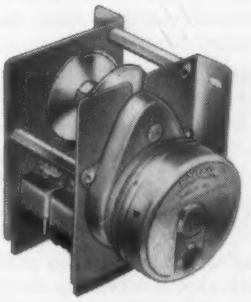
## TIME DELAY TIMER

*Provides time delay in ranges up to 9.5 minutes. Ideal for such applications as the protection of power tubes and/or operating preset operating cycles. Available in 120 or 240 volt, 50 or 60 cycle current.*



## 400 CYCLE MOTOR

*These split phase motors provide the military an accurate approach to timing control for military applications. Rotor speed is 3,000 RPM at 400 cycles, 115 volt normal. Two models are available — Heavy Duty with 18 gram millimeters torque at the rotor, and the Miniature with 5 gram millimeters at the rotor. These motors may be applied to Haydon gear trains if desired.*



## CYCLE TIMER

*These units repeat a set cycle or sequence of operations as long as the motor is energized. Available in a wide choice of speeds, a broad range of timing intervals, and with a wide range of enclosed single pole, double throw switches for 120 and 240 volt operation, for 50 and 60 cycles.*

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† Patent applied for.

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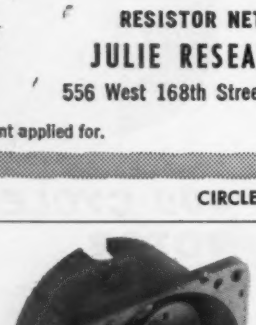

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Link's Hi-Precision 012 Gear Boxes offer the flexibility, performance range and construction qualities you'd expect to find only in costly custom systems. Designed for application with servo mechanisms, control equipment, instruments, computers and motor drives, Link 012 Gear Boxes are light (16 oz.) and compact (3½" x 3½" x 2-7/32"). They feature anodized aluminum AGMA Precision Class 3 gears, Class 1 precision ball bearings and lifetime lubrication.

**Other Model 012 Features:**

- Output rated at 120 oz. – in. at slow shaft
- Friction torque of .004 oz. – in.
- Backlash less than .27°
- Avg. total inertia (reducer & coupling) 4.5 gm cm²
- Efficiency 97% at 120% rated load; 95% efficient at 10% rated load
- Available in ratios from 5:1 to 3125:1

Dual output models also available for many ratios . . . Link adapter kits integrate 012 Gear Box with commonly used servo motors.

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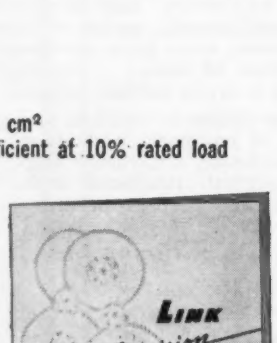


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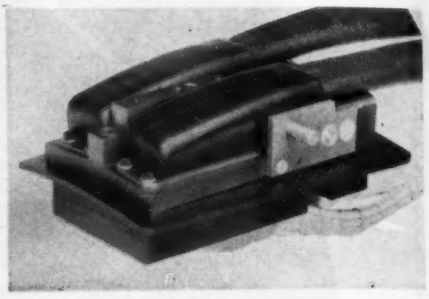


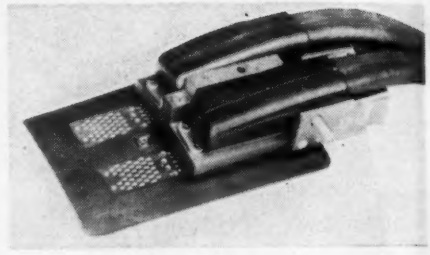
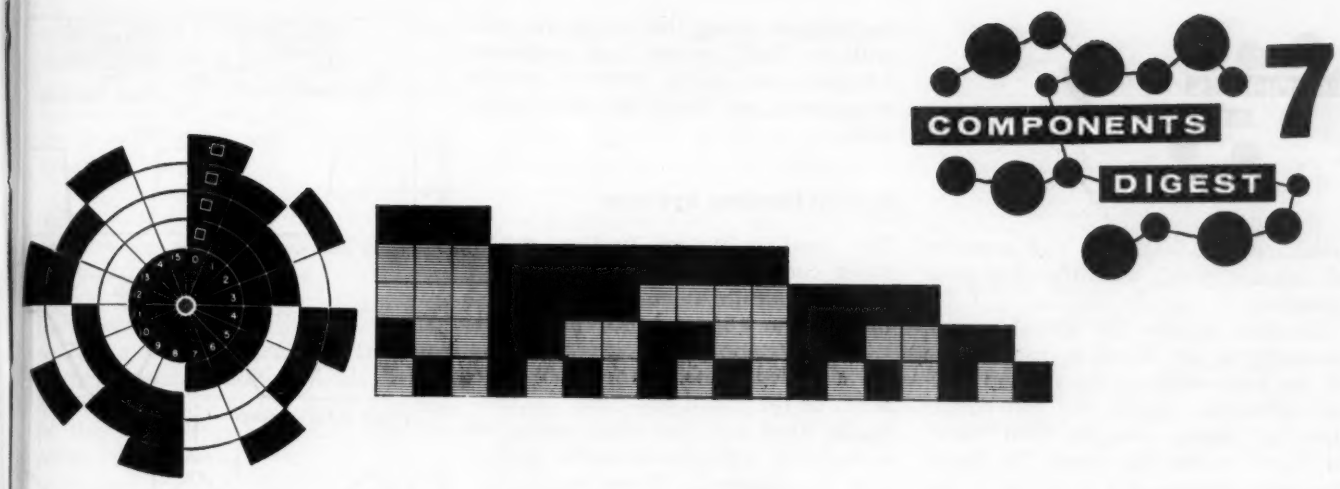


**Fig 11 Wiggins' shear type of connector design is based on a 3-spring, phosphor bronze leaf design that supplies a popping action upon release of the connector. Wiping action of the spring leaves during disconnect delivers a smooth clean break with no pin friction. The unit disconnects by missile motion during fire between 0 and 90° to the surface of the missile with a force of 25 lbs on lanyard or fail safe with a force of 600 lbs on the retract trunnion. This particular design is integral to the missile skin and forms a part of the stress bearing structure; the connecting surface is electrically isolated upon disconnect. Two ½" water methanol electronic cooling lines for the guidance package are integrated into this particular umbilical connector (L23P6).**

disconnect mechanisms are activated by an electrical impulse that explodes a squib on the connector. Detonation of the squib disconnects and ejects the connector halves.

Fig 10 shows a series of four basic release mechanisms illustrated by Cannon Electric. Fig 11 shows E. B. Wiggins Oil Tool Co.'s shear type of umbilical connector. (Pages 4 and 5 of May, 1959 ELECTROMECHANICAL DESIGN contains the detailed description of some new E. B. Wiggins' quick connect-disconnect designs for patch panels and missile fire control systems.) Wiggins also designs special pod panel assemblies that include not only electrical connectors for jet aircraft checkout, but also contain hydraulic, fuel and other types of non-electrical connectors.

*END*




# Analog-Digital Converters—Part 2

*The sections of CD 7 Part II are derived from two main sources: "Notes on Analog-Digital Conversion Techniques", edited by Alfred K. Susskind and published jointly by the Technology Press of Massachusetts Institute of Technology and John Wiley and Sons, 1958; and information furnished by engineers at EPSCO, Inc., Cambridge, Mass. The source of each section is noted in the text.*

Part I of Components Digest No. 7 in the June issue of ELECTROMECHANICAL DESIGN was restricted to shaft position encoders, which convert an analog shaft input to a corresponding binary digital output. In these devices, a coded pattern disc with concentric rings corresponding to digits, having alternating conducting and non-conducting segments corresponding to binary 1 and zero, is coupled to an input shaft whose angle is to be measured. Read-out devices corresponding to the individual concentric rings, determine whether the corresponding discs are binary zero or one. In Part I, the details of the construction and operation of these devices were considered. Emphasis was on those devices in which brushes are used to read out the individual digits. Techniques using internal and external logic elements were also described which provide great flexibility and may be used in a great many codes. Compact logic circuits are available which deliver a pure binary output in non-ambiguous form.

A second major type read-out technique is based upon the use of optics. In place of brushes running on disc segments, the optical type has a pattern of opaque and transparent areas that can be read by placing the disc between a light source and a photo cell array. An optical slit establishes the width of the "brush" in optical readings. By their nature, many of the logic circuits which have been quite feasible using brushes are not practical in the optical case. For this reason, optical-type devices avoid the ambiguity problem by employing a non-ambiguous code such as the reflected or gray code.

### Comparison of Brush and Optical Type Shaft Encoders

In chapter 6 of "Notes on Analog-Digital Conversion Techniques", John Ward examines typical commutator and optical codes to establish the level of mechanical tolerances required in manufacture and in use to keep equivalent brush width within one quantum.

Perhaps the most serious ambiguity problem arises, Mr. Ward says, in the commutator pattern coders as a result of variations in brush alignment. Brushes are susceptible to vibration and acceleration forces, which can cause intermittent contacts and shifts in brush position. Since shaft friction, resistance to mechanical disturbance, and operating life all are functions of the brush pressure, a compromise must be made among them in the design of a coder. Resistance to mechanical forces can in general only be obtained at the expense of increased friction and lowered operating life. Also, it is found difficult to fabricate multiple-brush assemblies for reflected binary commutator coders with sufficient built-in accuracy, and adjusting screws are usually provided so that the brushes may be individually adjusted during the final tests of the coder. Brush alignment, therefore, is a problem not only in the original manufacture of commutator coders, but a continuing problem as vibration and brush wear tend to move the brushes from their original positions. One quantum in a three-inch diameter ten-digit code disc is about 0.010 inch, and a typical brush width is about 0.005 inch. Brushes must be positioned within about 0.002 inch if any allowance is to be made for the contributions to equivalent brush width of pattern errors, shaft eccentricity, etc.

Ward points out that most of the above problems with brushes are eliminated in an optical disc with a photoelectric reading method. Since there are no rubbing contacts, there is no wear problem and no limit on the disc life or disc operating speed. The photocell assembly and optical slit can be made more rigid than the brushes of a commutator coder, and slits can be made extremely straight and of constant width by using a ruling engine. The problem of relative slit alignment between zones is therefore not troublesome in optical coders, except that the reduced dimensions of the segments make the tolerances on slit alignment very small. For example, in a typical thirteen-digit reflected binary coder with a 2.75-inch diameter disc, a segment on the thirteenth zone is 0.0018-inch wide, and a quantum is therefore 0.0009-inch wide. The 0.0006-inch reading slit must be radial with a

COMPONENTS DIGEST 7

tolerance of 0.0001-inch and must be of constant width to within the same tolerance.

Another problem in optical coders, according to Mr. Ward, is that because of the finite width of the slit and optical diffraction effects, the cell output does not change abruptly from "dark" to "light" as the disc moves. To detect the exact position of a transition in the pattern, an external amplitude discriminator is required at the cell output, and variations in the discrimination level add to the equivalent brush width.

Despite the advantages of optical coders with respect to reading resolutions and accuracy, Mr. Ward says, the optical coder has some new problems of its own. The reading system is more complicated than a commutator and brush system and is thus perhaps just as likely to give trouble, although for different reasons. Discs may be read either by flashing the light or by using a steady light and turning the photocells on and off. If a flash lamp (usually xenon) is used, the coder requires a high-voltage power supply which may be troublesome in some applications. Also, cell outputs with flash excitation are so small that an amplifier is required in each cell output, and gain stability is required to maintain a small discrimination band. If a steady light is used, cell output can be improved, but the discrimination circuits must now be able to distinguish a "light" cell from a "dark" one under all conditions. Two methods for doing this are to use cells with no "dark" output (e.g., cadmium selenide), or bridge detector circuits to suppress any "dark" output from the cells.

## Optical Reading Systems

The reading system for an optical coder consists of: (1) a light source (2) an optical system, which forms an index beam (3) a detector, which is used to determine the index position on a coded plate. Either the index beam or the coded plate may be arbitrarily fixed and the other moved in accordance with the measured parameter. In chapter 7, "Notes on Analog-Digital Conversion Techniques", John W. Brean and Martin S. Osman discuss some major considerations in design of optical encoders.

They point out that a number of basic optical systems can be used: Fig. 1 shows one such system. Here a point energy source is used to illuminate a cylindrical lens. The energy collected by the lens converges at the coded surface and the image formed acts as the index. A narrow optical slit is placed between the coded surface and the multi-element detector to prevent unwanted light from reaching the detector. The logical moving part in this configuration is the code plate.

Figure 2 illustrates another reading system. Here a line source is used to irradiate the coded surface. An optical slit similar to the one used in the previous figure is placed between the coded surface and the detector. In this case, the slit forms and determines the dimension of the index; the light radiated from the source in directions other than the straight path to the slit is prevented from reaching the detector.

Other optical systems can be devised to perform the same operations. However, it is desirable that the system chosen should occupy minimum space and be as simple as possible, particularly for airborne applications. The system in Fig. 2 is simple, but it is relatively inefficient since only a small amount of the energy radiated from the source is useful. The space requirement of a particular system, however, sometimes demands acceptance of its inefficiency.

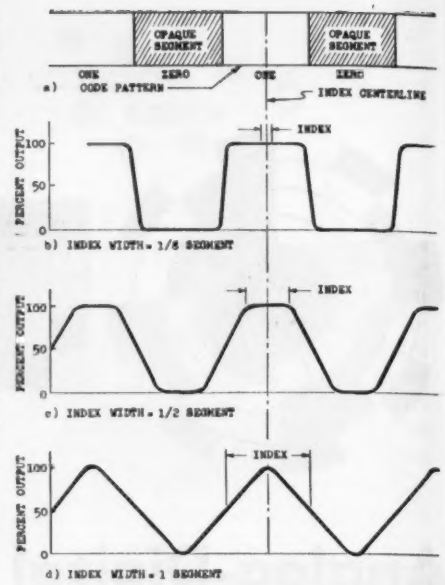



**Fig 3 Detector response for the zone vs index position for three index widths**

In the design of the reading system, according to Brean and Osman, consideration must be given to (1) the index width and its alignment, (2) the viewing angle of the detectors, and (3) cross-talk between zones. Here is their discussion of these considerations.

### INDEX WIDTH AND ALIGNMENT

In any visual reading system, the width of the index acts as one of the limiting factors in the resolution of the reading system. For instance, when a voltmeter is equipped with a coarse pointer, the physical center of the pointer must be estimated in order to provide a precise reading. The accuracy of the reading then is no better than the estimate made on the center-line position of the index.

The same limitations exist in the

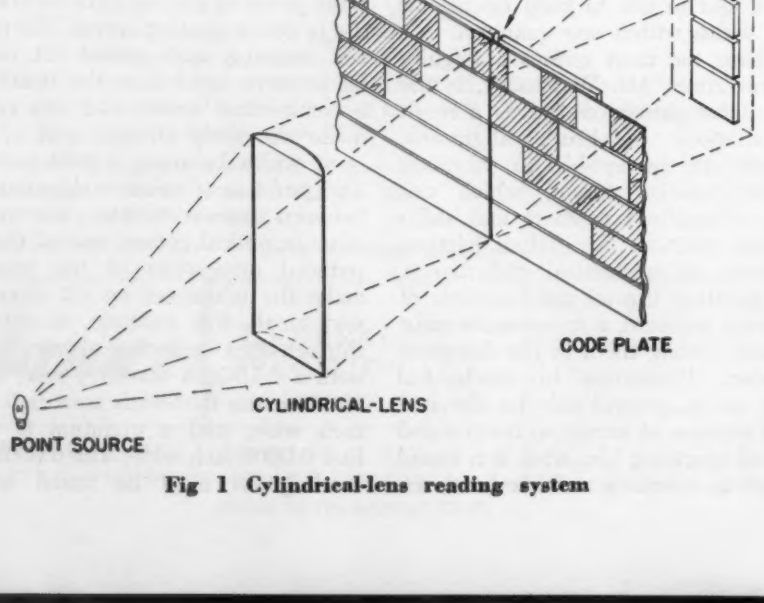



**Fig 1 Cylindrical-lens reading system**

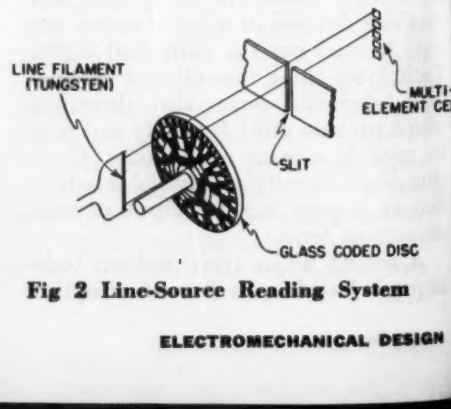



**Fig 2 Line-Source Reading System**

optical coder reading systems. Here delineations must be accurately made between the two sides of the segment boundaries in each zone. The index width may be regarded as equivalent brush width.

The zone-to-zone alignment of the index also enters into the problem of reading. In general, the code pattern is constructed in such a fashion that it can be properly read only by an index which is exactly perpendicular to the zones. Any deviation from this perpendicular condition adds to the equivalent width of the index and also to the ambiguity in reading the segment boundaries.

A good reading index must interpret the code pattern and determine the points where transitions exist with the same accuracy that the transitions are arranged in the code pattern. It is evident, then, that the greatest definition and resolution can be achieved through an index whose width is infinitesimal and whose alignment is exactly perpendicular to the zones. An infinitesimal index is impractical, since the transmitted light flux would be limited; consequently, a finite width must be established. As the width of the index is increased, however, the reading ambiguity at the segment boundaries also becomes greater. The effect of various index widths may be seen in Fig. 3, which shows the modulation envelope of the light flux transmitted through one zone as the index is moved. It is obviously necessary to restrict the effective index width in an optical coder to the width of the smallest division in the code pattern. This is the maximum width that permits the reading of the most finely divided zone without seriously impairing the ONE-to ZERO signal ratio obtained in the least significant code channel. Notice that the actual change in photocell response at a code transition is smooth rather than abrupt, as would be true in a perfect reading system. As the effective brush width is made smaller and smaller, the change in photocell response at a code transition more nearly approaches the ideal abrupt change, but progressively less energy reaches the photosensitive surfaces.

### VIEWING ANGLE

In any reading system the viewing angle must be constant for all observations. In the more precise visual reading systems, a mirror is sometimes placed behind the index, which permits alignment of the index and its image before making the observation. The viewing angle is then always the same and parallax errors are prevented. In electro-optical systems, the viewing angle is held constant by controlling the angle of energy transmission through the code pattern to the detectors. This must be accomplished by the index-forming components and by limiting the size of the source. It is also important that the detectors do not receive energy from areas of the coded pattern which are not irradiated by the index.

### CROSS-TALK

The position and length of the source must be such that cross-talk (the transmission through a zone of the pattern to an adjacent detector) cannot occur. The restrictions on the permissible positions of the energy source are illustrated in Fig. 4. Part (a) of the figure shows a cross section of a four-zone coded pattern and its associated detectors. The shaded area above the line AB represents the positions for a light source which do not result in cross-talk between a zone and any zone above it. In part (b), the shaded area below the line CD represents the positions for the light source which do not result in cross-talk between a zone and any zone below it. Part (c) represents a superposition of Parts (a) and (b) and the resulting shaded area represents the permissable light source positions in which no cross-talk can occur. A point source can be placed anywhere in this area and a line source can extend to the boundaries. A point source which radiates sufficient energy is difficult to achieve. In order to maximize energy which can illuminate the

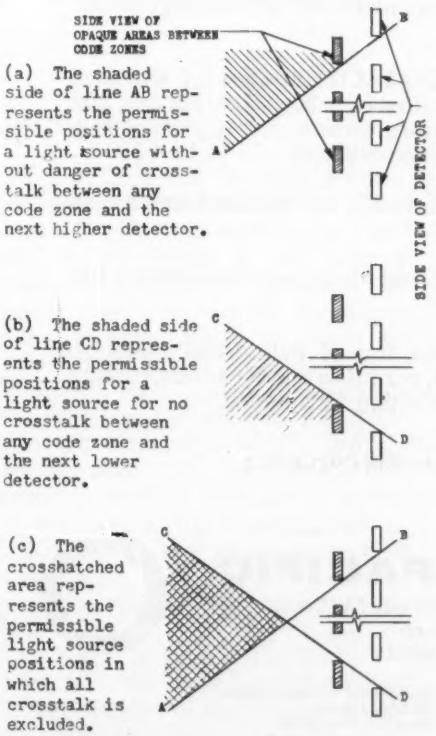

SIDE VIEW OF OPAQUE AREAS BETWEEN CODE ZONES
(a) The shaded side of line AB represents the permissible positions for a light source without danger of cross-talk between any code zone and the next higher detector.
A
B
SIDE VIEW OF DETECTOR
(b) The shaded side of line CD represents the permissible positions for a light source for no crosstalk between any code zone and the next lower detector.
C
D
(c) The crosshatched area represents the permissible light source positions in which all crosstalk is excluded.
C
B
D

**Fig 4 Cross-talk restrictions on lamp positions**

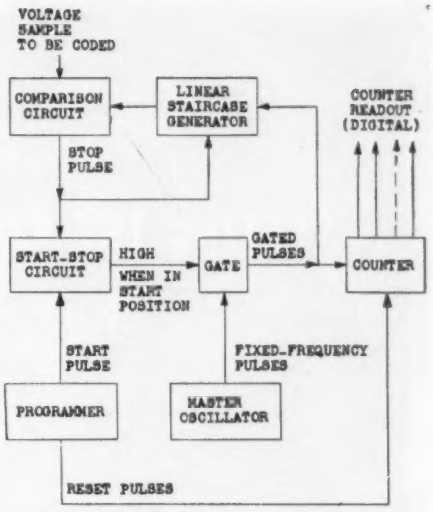



**Fig 5 Block diagram of coder similar to anodige**

detecting surfaces, the lamp radiating element should be as large as possible commensurate with the cross-talk and viewing angle constraint. That is, the source length must be limited in accordance with Fig. 4 and in addition its width (the source dimension perpendicular to the page) must not allow illumination of the detectors through segments not illuminated by the true index. Normally the viewing angle is limited by the slit or some other optical component. It appears then that a line is the most suitable source configuration. The cross-talk criteria can be used to determine the maximum length of the source once the dimensions of the code plate and detector assembly are fixed, and the viewing angle will determine the source width. If a point source or a short filament are used, the distance from source to code plate must be adjusted to permit proper illumination of all detectors through their associated zones and to avoid cross-talk.

## Voltage Encoders

A variety of techniques is available for expressing a voltage in its corresponding digital form or deriving a voltage which is proportional to a number. In chapter 5 of "Notes on Analog - Digital Conversion Techniques", Alfred K. Susskind surveys these techniques and organizes them in two major categories: voltage coders and decoders in which there is an intermediate conversion into a time interval, and voltage conversion devices in which no intermediate conversion is made.

Mr. Susskind points out significant differences in the characteristics of the two groups. Members of the first category (time representation involved)

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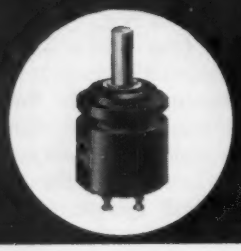

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perform the conversion in a relatively long time (hundreds to thousands of microseconds). They result in relatively complex conversion devices, but where several information channels must be handled, the conversion-equipment cost per channel is only moderate, because some of the required components can be used by more than one channel. In the case of decoders, "holding" of the output without recourse to storage of the number to be converted can be achieved.

Members of the second category (time representation not involved) are characterized by short conversion time (a few microseconds or sometimes only a few tenths of a microsecond). These converters can only be shared by several channels through switching at the input or output. In order to achieve holding, decoders in this category require storage of the numbers to be converted.

It appears that most voltage converters have essentially the same upper limit in accuracy. Susskind says, where space, weight, and environmental specifications are not severe, it seems possible to achieve an accuracy of one part in one or two thousand with many of the techniques, regardless of category. That such a limit is reasonable can be seen he says, by realizing that part of any converter consists of electrical analog equipment which is always characterized by an upper accuracy limit of similar order of magnitude. It follows, he says, that the accuracy limit in the conversion poses no limitations in the over-all system, for the conversion accuracy matches the accuracy of the voltage signal to be coded or the accuracy requirements of any units into which a voltage decoder is connected.

### CODING BY INTERMEDIATE CONVERSION TO A TIME INTERVAL

*Anodige.* The block diagram of a voltage coder patterned after Anodige, a National Bureau of Standards development, is shown in Fig. 5. The principle of operation is as follows. The voltage to be coded is compared with a linear staircase voltage generated inside the converter. Each time a step is generated the contents of a counter are increased by one. When the staircase voltage agrees with the voltage to be coded, the counting

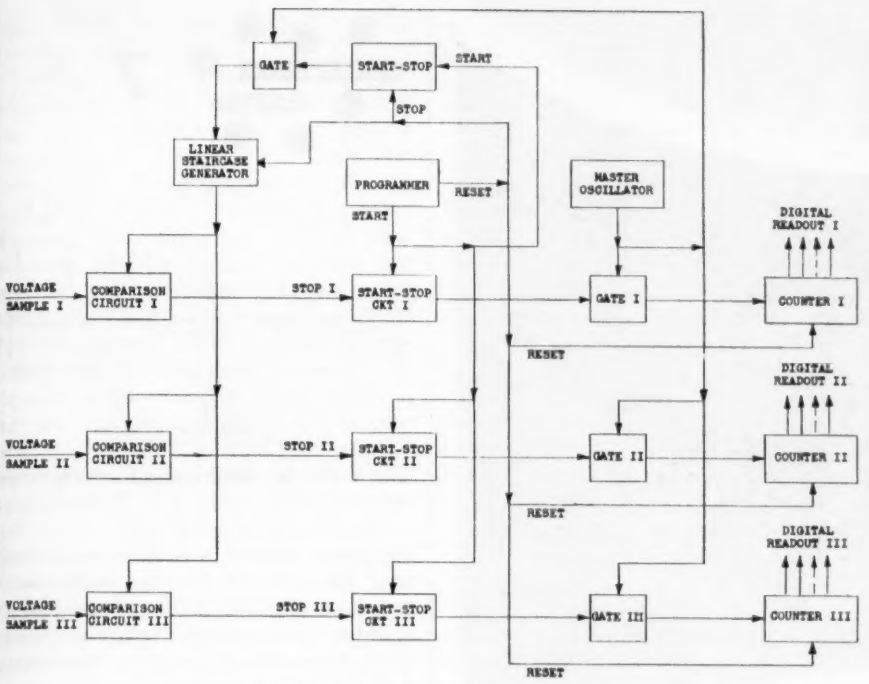


**Fig 6 Multiplexed anodige type coders**

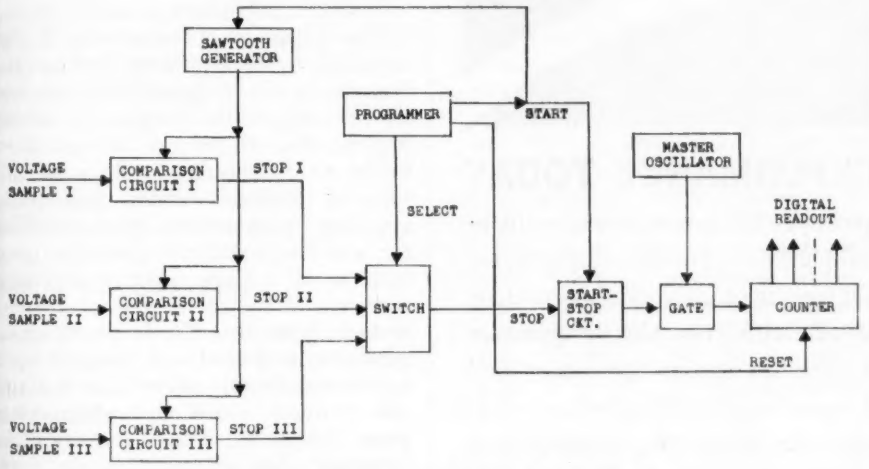


**Fig 7 Multiplexed-sawtooth comparison coder**

action is stopped. The number of counts accumulated is then proportional to the voltage to be coded and the counter readout is the desired numerical representation.

*Operation.* Assume that initially the output of the linear staircase generator is zero, the counter is reset to zero, and the start-stop circuit is in the stop position, which means that its line to the gate is at a low enough potential to block the passage of pulses from the master oscillator. When the programmer sends out a start pulse, master-oscillator pulses of fixed frequency pass through the gate. For each pulse, a step in the staircase waveform is generated and the contents of the counter are increased by one. This process continues until the staircase level agrees with the voltage sample to be coded. When the comparison circuit indicates agreement, it sends out a stop pulse that puts the start-stop circuit in the stop position, thereby shutting off the flow of fixed-frequency pulses through the gate and resetting the output of the staircase generator to zero. The contents of the counter may now be read. Some time after that, the programmer sends out a reset pulse to the counter, thereby clearing it, and shortly thereafter, a new start pulse is generated and the conversion cycle repeats.

*Characteristics.* The conversion time in this approach is determined by two primary factors: the counting rate, $r_c$, of the counter; and maximum number to be coded, $p_{max}$. Let the maximum conversion time be designated as $\tau_{max}$. Then

$$\tau_{max} = (p_{max}/r_c) + \Delta$$

where $\Delta$ is the time required to read out the contents of the counter and to reset it to zero. Since for a practical counter the highest operating rate is about 5 megacycles, and a reasonable

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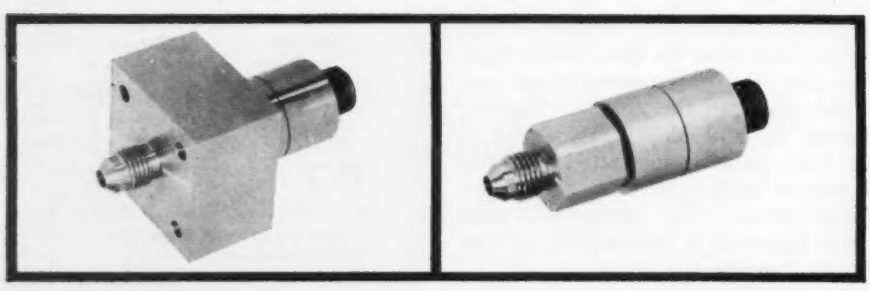

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**Fig 8 Block diagram of comparison coder**

minimum time for reading and resetting the counter is one microsecond, it follows that for a three decimal-digit number (ten binary digits) a reasonable lower limit on the conversion time for the largest number is

$$\tau_{max} = (1023/5 \times 10^6) + 1 \times 10^{-6} = 200 \text{ microseconds}$$

The accuracy of conversion is determined by two primary factors: the linearity of the staircase generator and the accuracy of the comparison circuit.

*Multiplexing.* If several voltages were to be coded simultaneously with this type of feedback coder, one could make the programmer, master oscillator, and linear staircase generator common to all coders. This arrangement is shown in Fig. 6 for a three-channel system. Note that the linear staircase generator is started and stopped by a separate start-stop circuit that initiates the staircase when the programmer starts the coding action and ends the staircase when all counters are reset. The reset pulse also returns the staircase voltage to zero.

### SAWTOOTH-COMPARISON CODER

*Operation.* In a modification of the approach described above, the linear staircase generator is replaced by a sawtooth generator and the voltage sample to be coded is compared with the output of the sawtooth generator. At the start of coding operation, the sawtooth waveform is initiated and counting of master-oscillator pulses begins. When the level of the sawtooth voltage agrees with the voltage of the sample, the comparison circuit stops the flow of pulses into the counter. Again, the count accumulated is proportional to the input voltage.

*Characteristics.* Because the operation of this coder is also based on measuring the time taken by a locally generated waveform to equal the voltage to be coded, the conversion time of the sawtooth-comparison coder is

equal to that in the equation for the Anodige-type coder.

In this coder as well as the Anodige-type coder, the comparison circuit and the local waveform generator govern the accuracy of conversion, since the error in measuring the time interval is negligible. When a sawtooth generator is used, the slope as well as the linearity of the output voltage are important. Slope matters because the coder measures, in terms of fixed- frequency pulses, the time interval required for the sawtooth to equal the voltage of the sample. Hence even if the sawtooth were perfectly linear, any variation in its slope would change the number accumulated in the counter.

*Multiplexing.* The sawtooth-comparison coder can be multiplexed in a manner similar to that previously shown in Fig. 6. Furthermore, if it is not required that all channels be coded simultaneously, the start-stop circuits, gates, and counters can be shared by connecting the output of each comparison circuit to a common start-stop circuit through a switch as shown in Fig. 7. Note that this switch handles only pulses. Since the information resides in the timing of the pulses and not in the amplitude, the switch causes no loss of accuracy in the coder. Fig. 7 illustrates the large extent to which equipment can be shared in a coder with intermediate time conversion.

## CODING BY COMPARISON

The operation of a common class of coders is based on comparison of the input voltage with a locally generated voltage which is altered by a control circuit until the two voltages agree. The state of the local voltage generator at the time of agreement is read out in digital form and thus furnishes the desired number.

The block diagram of a comparison coder is shown in Fig. 8. The local voltage generator is a decoder, the voltage or current sources in which are turned on or off by the control circuit. The control circuit turns on various combinations of sources until the decoder output and the voltage to be coded agree. At that time, the states of the sources indicate the desired number. A source which is turned on causes a ONE to be read out and a source which is turned off causes a ZERO to be read out. Any of a great variety of decoders can be used here.

As a simple example, consider a three-digit binary coder which is designed to handle inputs ranging from 0 to 7 volts. Three sources are needed in the decoder. The decoder output due to the most significant source is 4 volts, due to the next source, 2 volts, and due to the least source, 1 volt. For a coder input of 5 volts, agreement is reached when the most significant and least significant sources are turned on. Hence the digital readout is 101, which is correct.

The accuracy of a comparison coder is determined by the accuracies of the decoder and the comparison circuit. The conversion time is governed by the manner in which the control circuit develops the decoder output voltages.

There are three modes of control-circuit operation possible. In one, the control circuit contains a counter which turns on the decoder sources in the sequence in which numbers are built up in the counter. The comparison circuit stops the counting sequence when the decoder output and the voltage to be coded agree. For example, when a binary number is to be generated, the sources $S_0$ to $S_n$ ($S_0$ denotes the least significant source and $S_n$ the most significant source) are turned on in the following sequence: (1) $S_0$ (2) $S_1$ (3) $S_0$ and $S_1$ (4) $S_2$ (5) $S_0$ and $S_2$ (6) $S_1$ and $S_2$ (7) $S_0$, $S_1$ and $S_2$ (8) $S_3$ (9) $S_0$ and $S_3$ etc.

To generate an n + 1-digit number, a maximum of $2^{n+1}-1$ counts are needed. The conversion time is therefore fairly long.

In the second mode of control-circuit operation, the coder functions as a servo-mechanism. The comparison circuit is so designed that its output indicates whether the difference between the input voltage and the decoder output voltage is positive, negative, or zero. For a positive difference, the contents of the counter are increased, so that a larger voltage is

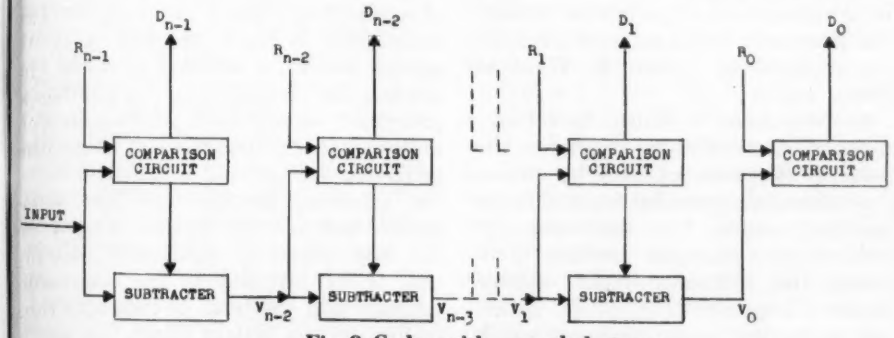


**Fig 9 Coder with cascaded stages**


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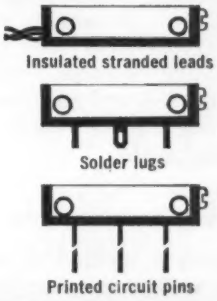


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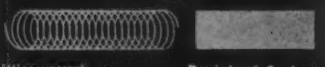

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generated. For a negative difference, the contents of the counter are decreased in order to reduce the locally generated voltage. These corrections are made until the comparison circuit finds zero difference. When the input voltage varies slowly enough so that the counter can follow the dynamics of the input, this mode of operation results in faster conversion than the one previously described.

In the third mode of operation, the most significant $S_n$ is turned on first by the control circuit. If the error is positive (input voltage greater than the decoder output), $S_n$ is left on; while if the error is negative, $S_{n-1}$ is turned off. The control circuit next turns on $S_{n-2}$ and the process is continued until all sources have been tried. For an $n+1$-digit number, only $n+1$ steps are needed and so decoding can be done much more rapidly than in the counting mode.

### CODING BY CASCADED STAGES

Fig. 9 shows a method of coding in which an n-digit number is derived by means of n single-digit coding stages in cascade. Each stage consists of a comparison circuit and a subtracter. The former compares the input voltage to a reference voltage, chosen to correspond to the value of the stage. If the comparison shows that the input is equal to or greater than the reference voltage, the comparison circuit reads out a ONE and the subtracter reduces the input voltage by the reference voltage. If not, a ZERO is read out and the input is passed on to the next stage unchanged. For binary numbers and quantization to q volts, the right-most stage uses a reference level $R_0$ equal to q volts and each of the other stages a reference level twice that of its neighbor to the right.

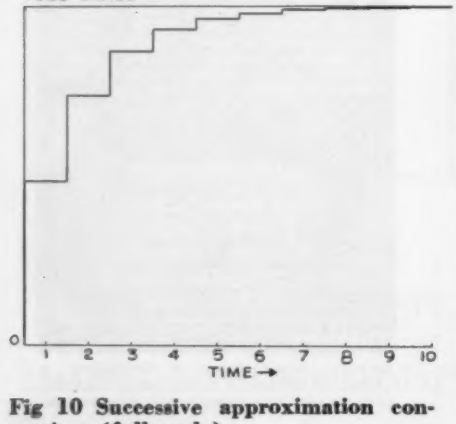


**Fig 10 Successive approximation conversion (full scale)**

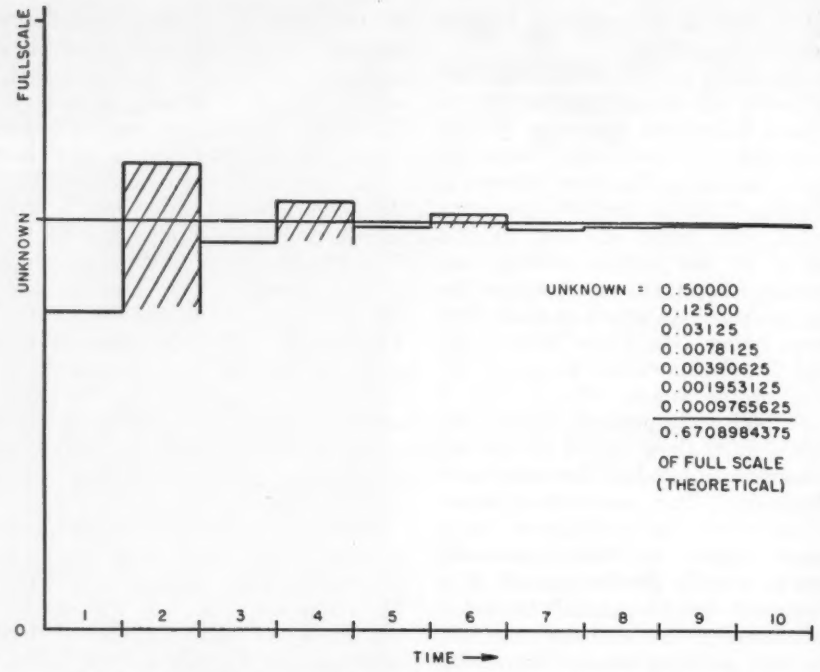


**Fig 11 Successive approximation conversion (0.671 full scale)**

The conversion time required by the coder with the cascaded stages is determined by the settling time of the n stage in series. A settling time of approximately one microsecond per stage seems realistic, so that it appears possible that a conversion time of only several microseconds is entirely within reason where moderate accuracy (e.g. 0.25 percent) is required. This coding scheme therefore leads to faster conversion than any of the others previously described.

Where the digital output is to be generated serially in time, a single stage can be used repeatedly to develop all the digits and a very simple coder results.

## Accuracy Considerations in Voltage-To-Digital Converters for Use in High Speed Systems

This section describes design and production methods for achieving optimum accuracy in a voltage-to-digital converter and outlines tests for establishing that a typical converter meets the design criteria of particular interest. The discussion is taken from information supplied by Robert E. Ward of Epsco, Inc.

The discussion is limited to voltage-to-digital electronic-type converters the majority of which operate by means of a successive approximation technique described above. The successive approximation technique involves comparing the unknown input voltage against a sequence of internally generated, accurately known voltages which

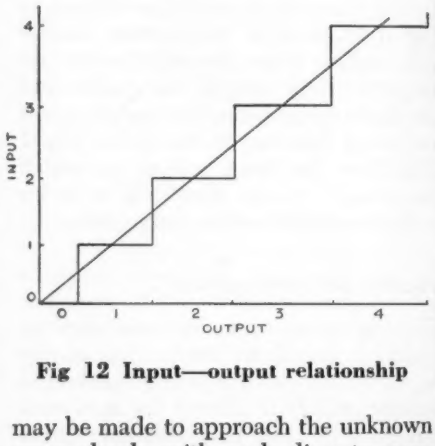


**Fig 12 Input—output relationship**

may be made to approach the unknown more closely with each discrete comparison. In a typical pure binary converter, the internally generated voltages used for comparison are related to one another as powers of 2. The sequence of comparison proceeds from the most significant bit which is equal to ½ of full scale, to the least significant bit which may be 1/512 or 1/1024 of full scale or smaller, depending on the resolution desired.

Each of the internally generated voltages may be applied to or removed from a summing junction under control of a switching register. As each discrete comparison is made through a comparator circuit, a decision is made regarding the magnitude of the internally generated voltage with relation to the unknown. If greater, the last internally generated voltage unit is removed from the summing junction and the next smaller unit in order applied. If smaller, the last internally generated voltage unit is left applied to the summing junction and the next in turn applied. In Fig. 10 Mr. Wright shows this proc-

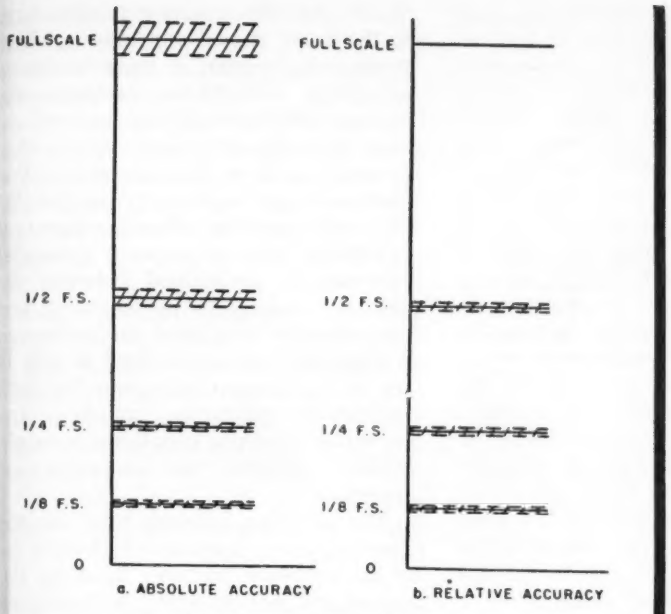


**Fig 13 Accuracy considerations**

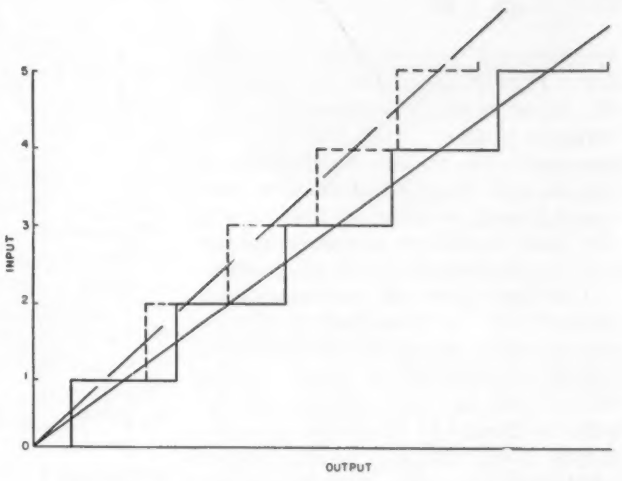


**Fig 14 Result of reference voltage error (low)**

ess for the simple case in which the unknown input is exactly equal to full scale. As each incremental unit of internally generated voltage is applied to the summing junction, it adds to those already present, resulting in an ever-increasing voltage appearing at one side of comparator circuit. The output of the summing junction, therefore, approaches ever more closely to equality to the unknown input voltage. The process is shown for a 10 binary bit voltage-to-digital converter. In Fig. 11 Mr. Wright shows the same process for the measurement of an unknown voltage, roughly two-thirds of full scale. The shaded portions in the drawing indicate voltage units, which, when applied, cause the output of the summing junction to exceed the unknown and which were, therefore, removed before proceeding.

The following discussion of accuracy by Mr. Wright relates to this successive approximation type of measurement instrument.

## ACCURACY CONSIDERATIONS

The ideal analog-to-digital converter should be an instrument whose output increases in arbitrarily small, precisely equal steps linearly related to an increasing input voltage as illustrated in Fig. 12. The straight line in the figure represents the linearly increasing input while the step function is indicative of the discrete changes in output value.

There are two fundamental sources of error related to the generation of the internal voltages used for comparison. The voltages generated are fractions of some full scale value and both the fractions and the full scale value itself are subject to error. Fig. 13 illustrates the results of such errors. In Fig. 13(a) an indeterminacy of error in the full scale value represented by the shaded portion results in progressively smaller indeterminacy areas about each of the fractional values of full scale, assuming each fractional value to be correct. In Fig. 13(b) the inherent inaccuracy in any fractional value is illustrated with reference to a fixed full scale value. These two sources of error may be cumulative. Referring again to the input/output relationship of a converter, Fig. 14 illustrates the effective result of a low reference voltage. It is interesting to note that this figure also indicates the possibility of using the reference voltage effect as a method of scaling inputs. Mathematically, the value of the reference voltage with relationship to an absolute value can be used as a constant multiplier to scale inputs either up or down.

The accuracy requirements for each of the fractional values is a constant in the absolute sense. That is, the half full scale value must be accurate to $\pm X$ volts and the 1/256 full scale value must also be accurate to $\pm X$ volts. However this works out percentage-wise to be a differing requirement for each of the resistors in the dividing network.

The ability of a successive approximation converter to resolve a given reading is a function both of the value of the least significant bit, and the ability of the comparator circuitry itself to detect differences as small as the least significant bit. In higher accuracy units, the comparator circuit generally sets the upper limit on resolution. The ability of the comparator to resolve differences on the order of the least significant bit has a definite effect on

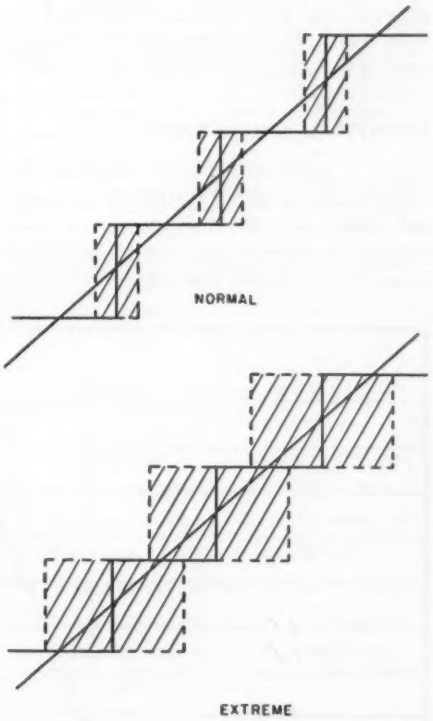


**Fig 15 Result of comparator imprecision.**

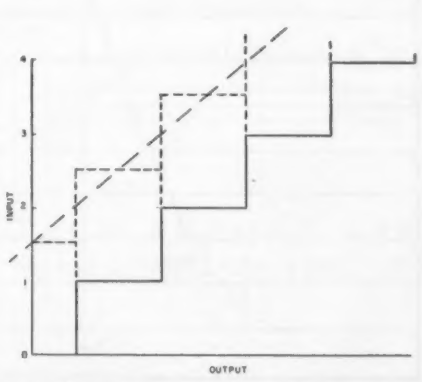


**Fig 16 Result of zero shift or offset**

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measurement repeatability and linearity. Fig. 15 illustrates the effect on the input/output relation of the converter as a result of the instability and low resolution in the comparator. It can be seen that in the extreme case, a unit having an apparent resolution to the least significant bit may not be able in practice to fulfill its promise.

The last source of inaccuracy considered may be described as a zero shift or offset. When an unknown input voltage is referred to some ground which is not an electrical equipotential with the ground to which the reference supply is referred, a constant offset is introduced to all readings taken. Mathematically, this is equivalent to addition of a constant value to all readings taken, where addition includes subtraction. Fig. 16 illustrates the results of such an offset on the input/output relationship of the converter.

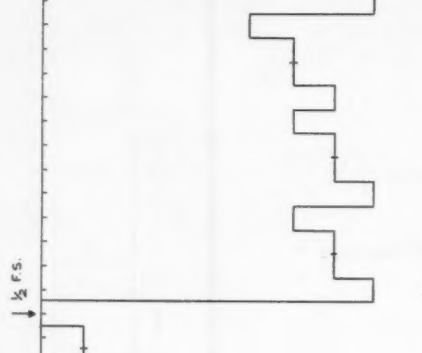


**Fig. 17 Number of bits vs output (10 bit converter)**

#### PRACTICAL LIMITATIONS

From a point of view of absolute accuracy, one part in 10,000 is a practical limit for the calibration of secondary standard equipment. This figure takes into account the use of precision components throughout, and allowance for their original inaccuracies, the effects of aging and the temperature variation. Solid state components such as diodes and transistors exhibit definite changes in characteristics over long periods of time. Zener diode references may exhibit changes of as much as 0.03 percent/degree F temperature change.

While absolute accuracy as referenced to the International volt may not be a prime requirement, it must be recognized that even relative accuracy may change with time and temperature and must be rechecked from time to time if accuracy is to be maintained. Precautions must be taken in the installation and operation of such equipment to assure that a properly grounded reference is maintained between the unknown voltage to be measured and the reference supply of the converter. A separate, highly stabilized supply to act as a common reference for both transducer excitation supplies and converter reference supplies is a recommended solution for maximum accuracy.

The dividing network used for the generation of fractional full-scale internal reference voltages must be designed and manufactured with extreme care. In high speed converters where the individual bit decision time is on the order of 2μsec, it will be appreciated that resistors must remain purely resistive at frequencies approaching 1 megacycle. The percentage requirement for accuracy is most acute on the most significant bit or ½ full scale bit and descends by powers of 2 with the smaller fractions of full scale. Thus, if 0.01 percent resistors be used on the ½ full scale bit, the equivalent requirement on the 10th bit is a 5 percent resistor. Strict adherence to these figures may still leave something to be required in the finished unit. It must be remembered that values such as 0.499 are built up as an internal reference voltage by summing as many as 9 fractional voltages in a 10 bit unit. The value of 0.500, however, is made up of only one fractional voltage. Thus, the designer must take care that the cumulative error as a result of summing fractional reference voltages not be allowed to exceed the single error inherent in any one of the fractional voltages. Failure to observe this rule has the interesting result that cer-

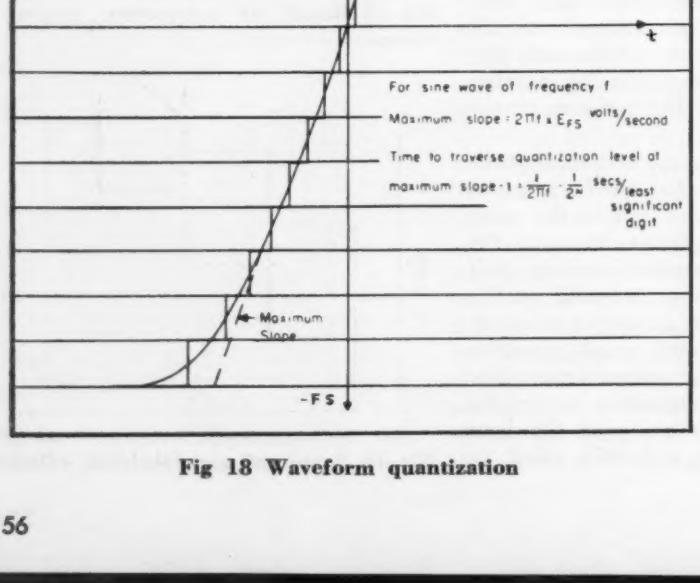


**Fig 18 Waveform quantization**

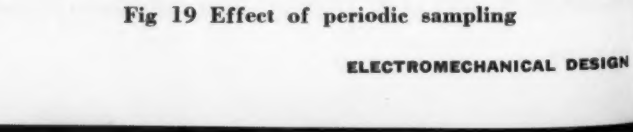


**Fig 19 Effect of periodic sampling**

tain output codes may be nonexistent. Missing codes are a rather severe form of instrument non-linearity. Fig. 17 illustrates the number of active legs in the summing junction for a range of outputs about ½ of full scale for a typical 10 bit converter. The base line used is one active leg since zero active legs occurs only at zero input. The height of the vertical scale can be considered to represent the relative magnitude of cumulative error for any given output reading.

The considerations discussed lead to certain conclusions regarding practical test programs to establish the accuracy of successive approximation type converters. Tests may consist of:

- Zero Check—with the converter input connected to the unknown input signal ground, the digital output should be zero.
- Absolute Check – the converter should digitize directly to within $\pm\frac{1}{2}$ the least significant bit any accurately known voltage source within the range of the instrument.
- Monotonicity (Linearity)—as the input signal to the converter is slowly varied from zero to full scale, the operator should observe that each and every possible output code exists over a stable range in proper sequence.
- High Speed Check—the converter should be able to accomplish test number 3 at its maximum design rate.

## SPEED REQUIREMENTS

Some factors that arise when analog information is converted into digital form are described for us by Bernard M. Gordon, Epsco President. He points out that the translation of temporally continuous analog data into discrete language (digital) notation implies that both the amplitude function and the time of measurement must be quantized.

In general, he says, analog information which is to be digitalized will have frequency components extending from a lower frequency limit to some upper frequency limit. The upper frequency components will impose the limitations on the accuracy of digitalization. Fig. 18 shows a half sine wave of frequency, f, and of full-scale peak amplitude. The maximum slope of the sine wave occurs as it crosses the zero axis. Here, the slope is such as to tend toward full scale amplitude in one radian; therefore, the maximum slope is equal to

$$2\pi f \times E_{FS} \text{ volts per second}$$

If the full-scale region is quantized into $2^n$ levels, then the minimum time for the sine wave to traverse one quantization level will be

$$1/\pi f \times 1/(2^n + 1) \text{ seconds per least significant digit}$$

Fig. 18 shows the quantizer will change its code whenever the voltage level comes within 50 percent of a quantization level.

Digitalization of analog information might then be carried out by noting the time at which a quantization level is changed and also noting the new quantization level. On the other hand, digitalization may be carried out by quantizing periodically at a rate sufficiently high to insure that the input information cannot change more than one least significant digit in one period. Mr. Gordon points out that the burden imposed by either of these approaches to digitalization is tremendous. For example, he says, to digitalize a 100-cycle sine wave to 0.05 percent peak error would require that approximately 600,000 data conversions be made per second.

It can easily be shown, Gordon says, that the error function for digitalization of this type is very closely approximated by a saw-tooth function of peak height equal to one-half the quantization level and further that the RMS error due to the quantization be very close to:

$$E_{rms} = 100/[(2)^{(n+1)}(3)^{1/2}]\ \%$$

It can further be shown, he says, that the spectrum of error information has most of its power well outside the original information bandwidth and that the original information can be almost completely recovered by passing the digitalized information through a filter which removes those frequency components lying outside the original data spectrum.

Now let S be the number of samples per second taken in the manner shown in Fig. 19. Here, the data is quantized and assumed to remain constant until the next quantization time. A mathematical investigation of recoverable accuracy, Gordon says, yields the following relationship.

$$\%\ \text{error} = 100[1 - (\sin\pi/s)/(\pi/S)] \cong 100\,\pi^2/6S^2$$

where S is the number of samples per information cycle of frequency f. Therefore, he says, to insure 1 percent accuracy in quantization for information channels which can have frequency components up to some frequency limit, it can be calculated that the sampling rate should be 13 times the upper frequency. For 0.1 percent accuracy the sampling rate must be 41 times the highest frequency present and for 0.01 percent accuracy the sampling rate must be 130 times that frequency. It is important to emphasize again, Mr. Gordon warns, that in order to recover the original information, the quantized data must be effectively filtered to remove frequency components above those present in the original wave forms.

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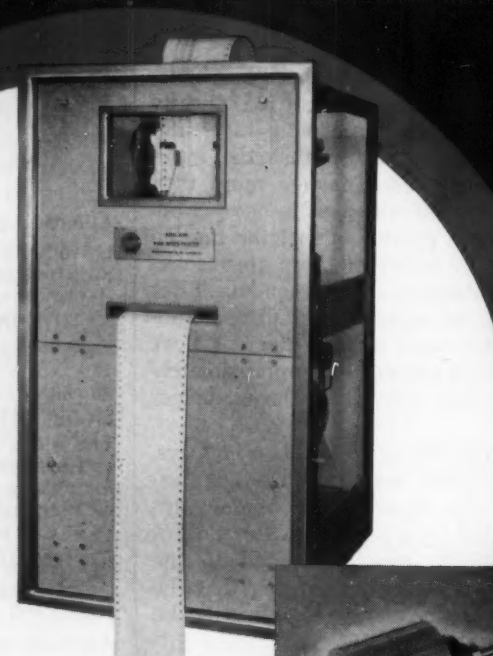

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The number of samples required per information cycle can be further reduced, Gordon points out, by employing more complex non-linear techniques in the data processing equipment. For example, he says, when a least mean square curve is fitted to a succession of sampled points, the original information wave form may be recovered to within 0.1 percent accuracy when as few as three samples are taken for each cycle at the upper frequency limit.

Now, Mr. Gordon concludes, when we consider these facts, the need for high speed data translation equipment becomes apparent. For example, as shown, to digitalize information containing significant frequency components up to 1,000 cycles will require that 3,000,000 data conversions be carried out per second, *if continuous quantization* is required, that 41,000 data conversions be carried out *if periodic sampling with linear filtering* is used and that at least 3,000 data conversions per second must be carried out even if more *complex non-linear interpolation* techniques are employed.

Mr. John LaFontaine of Epsco gives us another fundamental argument for the importance of high-speed translation equipment in industrial applications. A characteristic of typical industrial applications is that a number of parameters must be monitored to provide the necessary control information. LaFontaine points out that when a commutation device is used to provide a sequential output to a translator, switching noise transients will occur as the transition is made from one input to the next. Furthermore, any filtering or amplifying devices placed after the multiplexer require appreciable settling intervals. He concludes that if only a short noise-free period is available, a relatively high conversion speed is essential. According to both the nature and speed of the commutator, these transients will occupy more or less of each sampling period. Since it is not desirable to digitize noise or settling transients, a control synchronizer can be used to trigger the converter during the optimum noise-free portion of the switching interval.

Mr. LaFontaine illustrates this point in a specific application. Consider a problem of monitoring 400 data sources, some of which provide relatively dynamic input information; the commutator is to sample each source

approximately 2.5 times per second to prevent loss or misinterpretation of any of the input data. The sampling rate of the commutator, therefore, is 1000 samples per second.

For a dwell time for each sample of approximately 60 percent, or 600 microseconds, with switching noise consuming approximately 40 percent of this time, the useful noise-free sampling interval is reduced to 360 microseconds. Noise from other sources may be eliminated by means of a 3 kc filter, which reduces the available digitizing time to only 60 microseconds!

*Example*—To illustrate the arguments for high conversion speed Mr. LaFontaine describes application of a digital data averaging system designed by Epsco for a job which—on the surface—called for "low speed" measurement apparatus. In this application there was only one input parameter to be measured. This was the weight of a moving freight car.

The unknown weight is monitored by means of a conventional load cell. The voltage output from this cell is proportional to the weight of the car, modulated by any vibrations in the scale mechanisms and oscillations in the freight car being monitored. This information is sampled approximately 500 times by the DATRAC converter to effect 500 digital codes. At the DATRAC output each of these codes is transmitted through parallel lines to a binary counter. Subsequent to each counter preset operation, a gate is opened which passes that number of one-megacycle pulses which are necessary to run the counter backwards to zero.

The gated clock pulses employed for count down are routed, also, through a digital divider circuit and into a decimal accumulator. The division factor is set equal to the number of samples constituting one measurement, namely five hundred, so that the total number of pulses received at the accumulator input is the digital average of the five hundred data samples. When all 500 quotients have been accumulated, their binary-coded decimal sum is fed to a print-out device, where the four decimal digit average is displayed as an accurate measurement of the unknown weight.

When the car to be weighed moves onto the transducing apparatus, its motions and tremendous weight produces vibrations which result in noise transients of considerable magnitude and duration. Since the end desire is to operate the freight train over the measuring device as fast as possible, the transients occupy a major portion of the time the car is on the weighing apparatus. Thus the available sampling time is limited. While the high digi-


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